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Well Injection Depth Extraction (WIDE) Deployment at the Battelle Columbus Laboratories Decommissioning Project

Phase II Report
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NC STATE UNIVERSITY

DEPARTMENT OF CIVIL ENGINEERING
NORTH CAROLINA STATE UNIVERSITY

Well Injection Depth Extraction Deployment at the Battelle Columbus Laboratories Decommissioning Project

Phase II Report

for:
Battelle Memorial Laboratories

Submitted through:
Sauer Incorporated

Prepared by:
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EXECUTIVE SUMMARY

North Carolina State University's Department of Civil Engineering provided engineering support, through Sauer Incorporated, for the deployment of the Well Injection Depth Extraction (WIDE) technology at the Battelle's West Jefferson Filter Bed area, beginning August 2002 and continuing through April 2003. NC State's role was to provide design, construction, and engineering support of Phase II deployment effort. The field construction of the WIDE was performed by Sauer Inc, and US Wicks, and the overall project management was by Battelle.

NC State participated in field oversight during construction of the WIDE field in early September 2002. The construction activities involved the installation of over 2000 Prefabricated Vertical Wells (PVWs), fabrication and assembly of the surface piping manifold and header systems, installation and commissioning of the vacuum extraction and computer-controlled pump injection systems, and the configuration and hook-up of the 3M cesium filter system. NC State further supported the project by heading-up the commissioning efforts of WIDE system between November 2003 and April 2003. This report documents findings and work activities performed from August 2002 to April 2003.

After WIDE system installation, three phases of system commissioning are typically required as part of bringing the WIDE system on-line for remediation implementation; these three phases are: 1) Injection testing, 2) Extraction testing, and 3) Concurrent Injection/Extraction testing. During the current project period, only the first phase (Injection testing) of the commissioning program was completed and is reported herein.

The site's subsurface water table fluctuates with climactic conditions but was shown to be approximately six feet below the ground surface, over the project monitoring period. This subsurface water level is approximately four feet below the soil horizons with the majority of cesium contamination. As was previously planned, subsequent phases of the filter bed remediation will require the injection of a Battelle-designed Lixiviant into the subsurface for desorbing the bound radioactive cesium from the fine soil fraction. To support the Lixiviant implementation and injection into areas of concern (Lixiviant development was not a part of this study as it was developed by Battelle's PNNL) raising and sustaining the groundwater table at a specified elevation is needed in order maintain effective chemical retention (residence) time. Such time is of primary importance to facilitate desorption and removal processes. Field testing was focused at identifying key parameters to achieve this objective.

The field testing was staged on a pilot-scale area measuring 15 feet x 15 feet and positioned within Plot #2. Over the course of an 86-day injection program, commencing 20 November 2002 and ending 13 February 2003, a total of 29,072 gallons of water were injected into the subsurface in support of two testing cycles of the injection commissioning efforts. The testing cycles were: Cycle #1) Injection under gravity feed using a "falling-head" technique, and Cycle #2) Pressurized injection in both gradual and aggressive approaches.

Results from field testing showed that a multiple pulsed injection regime is preferred over single injection or gravity-feed injection for the purpose of saturating the subsurface for an extended period of time. The quickest groundwater mounding response occurred during the gravity-feed

injection mode. However, the mounding dissipated in a short period of time with a high declination rate. Gradual injection, using a pump, showed the longest time to achieve groundwater mounding, with the ability to maintain a longer saturation time as compared to gravity injection. The pulsed injection cycle using a pump showed the best results as this method yielded a groundwater declination rate that was one-third the rate with gravity injection, and approximately one-half the rate obtained using gradual injection using a pump. The low declination rate of the pulsed injection cycle, combined with a reasonable time for reaching maximum mounding, translates into optimum saturation and retention time for liquid injected into the subsurface given the site conditions.

Groundwater modeling was performed in order to gain a predictive perspective on possible impacts of injection scenarios and to understand the subsurface water movement. Results of the modeling showed a correlation between field data from injection/commissioning phase and the modeling output. The results of the modeling effort have far-reaching aspects for supporting the project field operations especially as Lixiviant is injected into the subsurface. One such aspect is the understanding of the subsurface liquid response to planned injection strategies, and development of configurations for the advancement of wetting fronts prior to injecting the Lixiviant. It is recommended that during Lixiviant injection phase, real-time monitoring coupled with modeling be used to control and direct the remediation work for effective implementation.

NC State further supported Battelle by maintaining operational documentation and furnishing supporting records, and preparing reports for the environmental compliance to the State of Ohio Underground Injection Control. Prior to using the WIDE system for remediation effort in Phase III, it is recommended that all three sequences of the system commissioning be tested. Information included in this report may be used for selecting operational parameters for calibrating the vacuum extraction system, optimizing the liquid injection parameters, and controlling the WIDE system hydraulic balance.

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PROJECT OBJECTIVE

The objective of this project is to deploy the Well Injection Depth Extraction (WIDE) technology for soil flushing of subsurface radioactive contaminants (primarily cesium) at the Battelle Columbus Laboratories Decommissioning Project (BCLDP) West Jefferson North (WJN) facility (JN-1 Abandoned Filter Bed). This site is a part of the US Department of Energy's (DOE's) Columbus Closure Projects (CCP). Battelle is remediating the Abandoned Filter Bed as a part of their NRC D&D plan to terminate the NRC Material License SNM-7. The North Abandoned Filter Bed area has been extensively characterized for radioactive constituents. The only radioactive constituent above free release levels is Cesium-137. The area had previously been remediated by excavating the leach field tiles and sand from the area and replacing with fill. However, residual amounts of cesium were entrained on the soil fines, and within the soil pores, during the re-grading effort. The Cesium contamination ranges from slightly over 15 pCi/gm to 200 pCi/gm in an area that is approximately 35 meters long by 20 meters wide by 2.5 meters deep. The contamination is mostly immobile as verified by monitoring wells and periodic sampling.

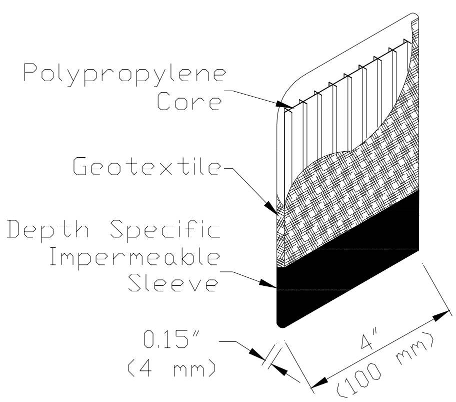
Flushing of the contaminants from the subsurface is to be accomplished using the Well Injection Depth Extraction (WIDE) technology and a surface separation technology that utilizes 3M filter disks for treatment. The WIDE deployment will encompass a 60 ft x 120 ft area near the Big Darby Creek, which is designated as Ohio pristine river. The in situ flushing methodology utilizes both water and a co-solvent (Lixiviant) to promote desorption through a closed-loop soil flushing system. The ultimate project goal is to assist Battelle in radiologically releasing the site for unrestricted use without disturbing the surrounding area. The phase of work reported herein is focused on system construction and commissioning.

The deployment of the WIDE system aims at the *in-situ* flushing of Cesium from the subsurface soil, at depths of 2-10 ft (0.67 – 3 m), with a closely controlled injection/extraction technique. The Cesium will be stripped from the soil fines by injecting a Lixiviant liquid and, within 2 feet of injection points, extracting the liquid out of the ground by vacuum. The WIDE system is designed to extract the groundwater, laden with desorbed Cesium, without the need for excavation and therefore avoids exposing the surface and underground soil to adverse environmental conditions such as wind, storm water, etc. Since site soils are not physically handled, packaged, or disposed of, this process should significantly reduce the radiological impacts to the environment, D&D workers, and the general public.

The Well Injection Depth Extraction (WIDE) technology was developed and field demonstrated through engineering and research funding from the US DOE – National Energy Technology Laboratory (NETL) OST #2172. WIDE is a technology under the Former Subsurface Contamination Focus Area (SCFA) and was field demonstrated at the US DOE Ohio Field Office, Ashtabula Closure Project (ACP) from 1997 to 1999, and with the US Army Corps of Engineers (Louisville and Nashville District Offices) at the Former Lockbourne Air Force Base located in Columbus, Ohio.

TECHNOLOGY DESCRIPTION

The WIDE system is a hybrid subsurface flushing/vapor-gas extraction system that uses Prefabricated Vertical Wells (PVWs) for the in situ remediation of contaminated groundwater and fine-grained soils with hydraulic conductivities ranging from 10^{-2} to 10^{-8} cm/s. The WIDE system has been field demonstrated for removal of groundwater having soluble contaminant waste streams, dense non-aqueous phase liquids (DNAPLs), light non-aqueous phase liquids (LNAPLs), and radioactive metals.



The major elements of the WIDE technology include the following: i) Prefabricated Vertical Wells, ii) Groundwater and soil vapor vacuum extraction system, iii) Liquid injection system, and iv) Above-ground treatment system. A typical PVW is manufactured as a composite system of an inner core, an outer permeable filter jacket, and at specified positions, an impermeable barrier sleeve.

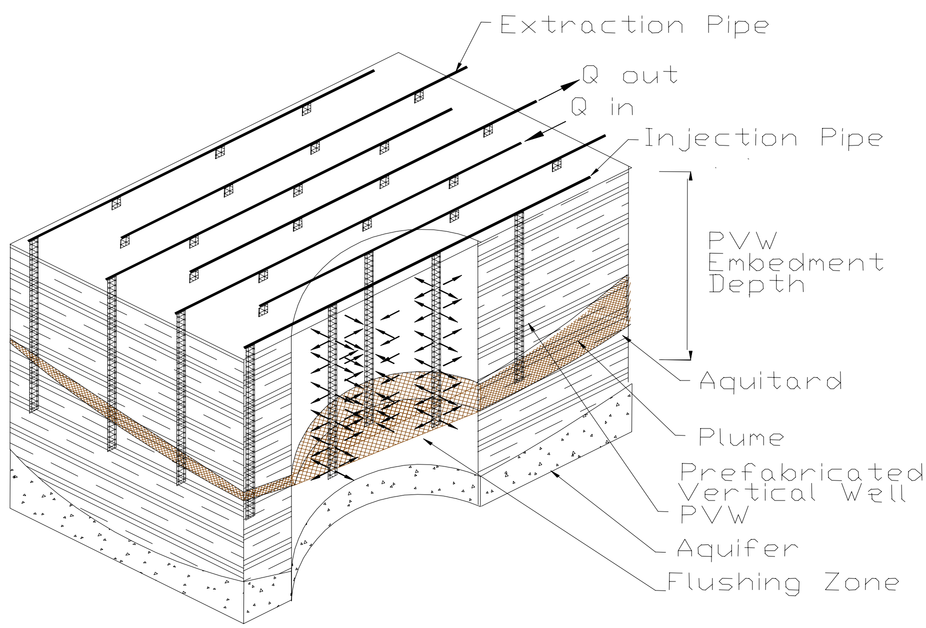
A PVW typically measures 100 mm wide by 4 mm thick, see adjoining figure. The core is constructed of extruded polypropylene and the filter jacket is typically a durable, non-woven polypropylene geotextile. The impermeable sleeving is made from reinforced chlorosulphanate polyethylene, a unique characteristic of the PVW. This design feature enables selective depth specific extraction and injection capability.

The WIDE system incorporates the PVWs as the mechanism for pressurized injection of a flushing solution into the in situ soil concurrent with vacuum extraction for removal of the contaminated solution. The PVWs shorten the groundwater drainage path, promoting subsurface liquid movement and thus expediting the soil flushing process.

The WIDE technology has the following advantages over conventional pump-and-treat remediation process:

1. Applicable to soils with low hydraulic conductivities (k: 10^{-3} to 10^{-8} cm/s).
2. PVWs can be utilized for depth-specific vapor extraction, liquid extraction, and liquid injection.
3. Installation of PVWs is rapid and inexpensive with no drilling required.
4. PVWs can be economically installed at relatively close spacing (< 3 ft), thereby shortening contaminant transport pathways.
5. Shorten typical pump and treat remediation durations.
6. Manufactured from existing off-the-shelf components, thereby minimizing cost and lead-time.
7. Targets the source points of a plume, thereby minimizing the volume of liquids being extracted.
8. Expedited contaminant recovery with reduced long-term operating costs.
9. Isolates workers from contaminated soil cuttings and injection/extraction gasses/liquids.

The WIDE system may function under concurrent injection/extraction, extraction only or injection only models. Balancing injection and extraction liquid volumes diminishes the potential for inducing compressive volumetric changes in the soil. Such changes reduce the hydraulic conductivity and leads to increasing the flushing time. The PVWs are installed using a hollow steel mandrel, which typically measures approximately 120 mm in width by 30 mm in depth, with lengths exceeding 100 ft The PVWs are positioned within the hollow core of the mandrel then the mandrel is pushed into the site soil under hydraulic or vibratory forces at rates of 3 ft/s in firm clay. A typical 10-meter (30 ft) deep PVW installation requires approximately 1 minute once set up is complete and no subsurface obstacles/anomalies are encountered during the installation process.



Well Injection Depth Extraction (WIDE)

Field construction typically entails a grid of PVWs in offset rows of injection/extraction lines at relatively close spacing depending on system design. The interval spacing and offset between the injection/extraction PVWs is based on engineering design and modeling as well as the specific objectives of the remediation effort. The PVWs are connected to a surface network of piping that is used for distributing air vacuum, receiving the extracted gases/groundwater, and introducing the injection liquids.

TECHNICAL APPROACH

The design of the WIDE system at Battelle's site incorporates the use PVWs as a mechanism for hydraulic head control through pressurized injection of a flushing solution into the *in situ* subsurface profile, concurrent with vacuum extraction. The flushing process will remove the soluble Cesium from fine-grained soil fraction. The Cesium is largely immobile at present within the designated remediation area as indicated by samples from groundwater wells.

The WIDE system at Battelle was deployed with the following major elements in a closed loop configuration:

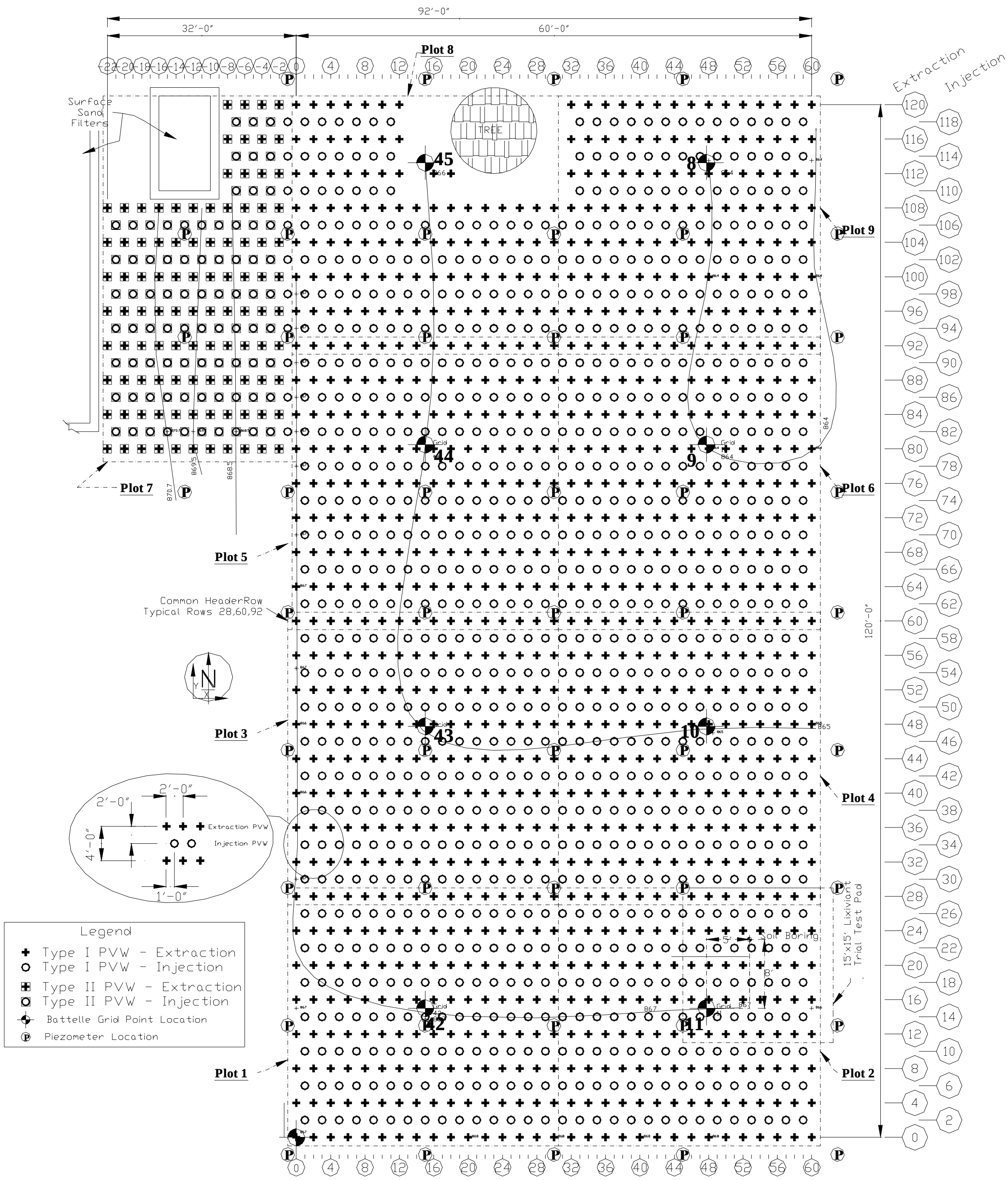
- Prefabricated Vertical Wells (PVWs),
- Groundwater vacuum extraction system,
- Liquid injection system, and above ground treatment and liquid storage system

The full-scale operation, once commissioned, will commence by flushing with potable water and, depending upon those results, will transition into flushing with Battelle-developed Lixiviant.

The field installation consisted of a grid of PVWs in offset rows of injection/extraction lines at relatively close spacing, two foot on center. The PVWs are connected to a surface network of piping. The surface piping system is used for distributing the air vacuum and receiving the extracted fluids, and also for introducing the injection liquids. The perimeter of the subject site is encompassed by rows of extraction PVWs. Thus, a vacuum boundary is established in order to assure further confinement of contaminants and flushing fluids within the remediation area, once Cesium is mobilized.

The field site is subdivided into plots (1 through 9) encompassing approximately 30 square feet each (refer to Figure 1: WIDE Field Layout). Similar to the overall WIDE field, the individual plots are constructed with extraction PVWs at the grid perimeter to assure perimeter groundwater recovery. The WIDE field should be operated on an individual grid basis and, in general, with no more than one to two grids at a time. The WIDE system was designed to function under concurrent injection/extraction, extraction-only, or injection-only modes. All extracted liquids are initially pumped from the extraction header into holding tanks. The extractant will then flow through two independent filter trains: a pre-filter train (a 100-micron filter preceding a 50-micron filter) to remove suspended solids before flowing through the 3M filter-train (a 2-micron roughing filter in front of a 0.2-micron filter), at a flow rate of less than 50 gallon per minute. The soluble Cesium will be sorbed to the filter media and the effluent will be pumped into effluent holding tanks. The effluent holding tanks are piped to the Lixiviant mixing tank for subsequent re-injection. The Lixiviant mix can then be held in a tank for re-injection as the flushing agent. Influent and effluent liquids will be monitored for Cesium concentration and Lixiviant pH throughout the project. Flow rates and the liquid volumes processed should also be monitored. Both the 3M treatment system and the Lixiviant mixing system will operate in batch mode.

Air quality will be maintained by installing two HEPA filtering units at the exhaust of the eductor system. Noise control will be maintained by the installation of a silencer at the eductor.



WIDE Deployment
Battelle WJ - Abandoned Filter Bed
Area JN-1

Figure 1: Wide Site Layout

SITE DESCRIPTION

During Phase I, field subsurface soil samples were obtained from a clean soil site adjacent to section 43 of the filter bed area of West Jefferson North Site. The site gently slopes toward the east, north east direction. Sampling was performed by Battelle using GeoProbe "direct push" technology. Three samples were taken from each of two borings to a depth of about 9.8 ft, one in the northeast region and one in the northwest region of section 43 of the filter bed area. These borings will be refereed to as "NE" and "NW", respectively.

The test borings were basically in the same soil series, separated by about 10 feet. Each 3 ft long sample was sealed top and bottom in a buteryn tube (which is the inner casing from a GeoProbe.) Depth and location of the samples were recorded on the outside of each 1-5/8-inch diameter tube. During sampling, the bottom two inches of the lowest 9.8 ft sample was wet; indicating the water table at sampling time was at a depth of approximately 9.8 feet.

Laboratory testing on soil samples shipped from the BCLDP site was conducted at the Constructed Facilities Laboratory-Centennial Campus of North Carolina State University. These tests measured soil characteristics necessary for the engineering and design of the WIDE system, as it is applied to the BCLDP site, for the purpose of fluid circulation and hydraulic head control. These tests were performed on samples retrieved from NE and NW borings. As the volume of samples was limited due to the limited number of borings, some of the soil samples were re-used within the testing program. While all samples used in testing were "remolded", care was taken to reconstruct the test specimens in the laboratory to field densities and moisture content.

Laboratory test results consist of both physical and engineering properties of the site soils. Physical properties tested include in-situ water contents and densities, specific gravity, Atterberg limits, grain size distribution and hydrometer analysis. Tests were performed in accordance with the following ASTM standards: in situ water contents – ASTM D 2216, specific gravity – ASTM D 854, Atterberg limits – ASTM 4318, and grain size distribution and hydrometer analysis – ASTM D 422.

The results indicated *in situ* moisture content to be less than 20%. The soil has slight to medium plasticity with a plasticity index that ranged from 8% to 20%. The grain size distribution indicated a percent fine of less than 10%. While the soil is classified as ML/SM/SW, depending on depth, it has less than 2% clay contents. However, the activity is relatively high which indicates active clay minerals. The coefficient of permeability was estimated to vary from 10^{-4} to 10^{-8} cm/s depending on depth. The change in the coefficient of permeability with decreasing void ratio should be a concern for the site soils. Furthermore, the results of the hydraulic conductivity testing indicated potential clogging of the PVWs fabric due to the marginal compatibility between the apparent opening size and the soil's grain size distribution. However, field operating condition may differ substantially from conditions under which the laboratory tests were run. The compressive strength of the tested samples decreased from approximately 57 kPa to 17 kPa with increasing moisture content.

TASK DESCRIPTIONS

The WIDE remediation support to Battelle is structured in four phases. This report addresses the completed efforts of Phase II. Phase I efforts consisted of site investigation and soil testing, project management directions, and design and fabrication of above ground system components. Phase II focused on mobilization and field construction of the WIDE system, operational startup, and commissioning of the pilot-scale system. Phase III is the operational phase and Phase IV is demobilization and project final-reporting. Project tasks completed under Phase II are organized below. (Many tasks are multi-phased, but are listed according to the phase in which they initially commence.)

Phase II: This phase addressed the field construction of the WIDE system and includes Sauer Incorporated and US Wicks field construction, and NCSU's engineering oversight efforts. In addition, work in this phase encompassed the commissioning (pilot operation) of the WIDE system and system startup to support soil flushing for remediation of the subsurface. The system was run through a series of injection optimization phases. Main tasks specifically undertaken by NCSU involve the following (Refer to the proposal for definition of tasks):

i. TASK 2. Assistance in Field Construction (supporting close-out of Phase I design/construction)
ii. TASK 3. Site Modeling
iii. TASK 4. Field Treatability Plan
iv. TASK 6. System Pilot Operation and Commissioning
v. TASK 7. Data Reduction and Reporting

Commissioning of the WIDE pilot-scale system involved a series of testing intended to bring the system into operational readiness. The commissioning effort was advanced at a pilot-scale level on a plot measuring 15 ft x 15 ft. Two testing sequences were performed and data were obtained for selection of parameters needed for injection/saturation process control and operation. The completed sequence includes Sequence 1: Injection-Only operation (gravity feed and pump feed). The details of this sequence are illustrated in Figure 2.

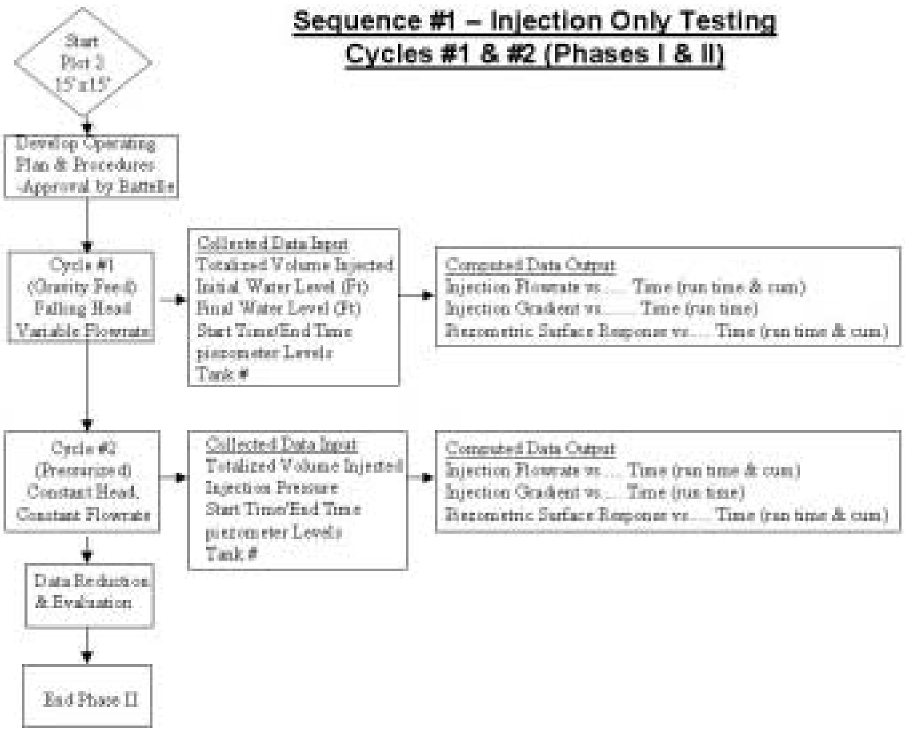


Figure 2: Process Flow Diagram Sequence #1 – Injection Only Testing

PILOT START – UP AND COMMISSIONING

The objective of the Injection Testing Sequence was to pilot test the system and to determine parameters governing the operation of the WIDE system at designed injection flow rates as well as the pressure needed to induce flow, attain saturation, and maintain piezometric levels to support subsequent flushing operation using concurrent injection/extraction mode. The test sequence in this case aimed at determining the water injection flow rates and pressures necessary to accomplish recharge of subsurface water table without damaging the soil physical structure. Potable water was be used for all injection operations. This testing sequence is divided into two test cycles described as follows:

Cycle 1:

This injection operation commenced on a limited scale using one quarter of the PVWs installed in Plot 2. Liquid injection was accomplished via a "Falling-Head" technique. This approach involved the injection of water by gravity feed. This was the lowest supply head possible to provide water to the PVWs for subsurface saturation.

Cycle 2:

This cycle of tests was performed on the same ¼ scale as Cycle 1 with a variation in the liquid delivery system. Here, a positive displacement pump was used to deliver a varying flow rate of water. The water injection flow rate was established at a corresponding injection pressure. Variations in flow rate and quantity were made in order to identify beneficial data trends for subsurface saturation.

The pilot startup was within Plot 2 in a 15' x 15' area as illustrated in Figure 3. This zone extended to include approximately 40 Prefabricated Vertical Wells (PVWs) between the boundaries of Row #12, Column 45, to Row #28, Column 60. The twelve piezometers installed within or adjacent to the test area were periodically monitored during the testing cycles to observe variations in the piezometric surface.

Testing sequences from the initial commissioning of the WIDE system are divided into subcategories based on type of injection process. Sequence 1, Cycle 1 testing occurred during the month of November and consisted of 3 days of gravity feed injection. Sequence 1, Cycle 2 testing occurred during the months of January and February and consisted of pressurized injection that was accomplished in either a pulsed or a gradual manner. In order to focus on the most important facets of field testing, only results from select days will be discussed in detail.

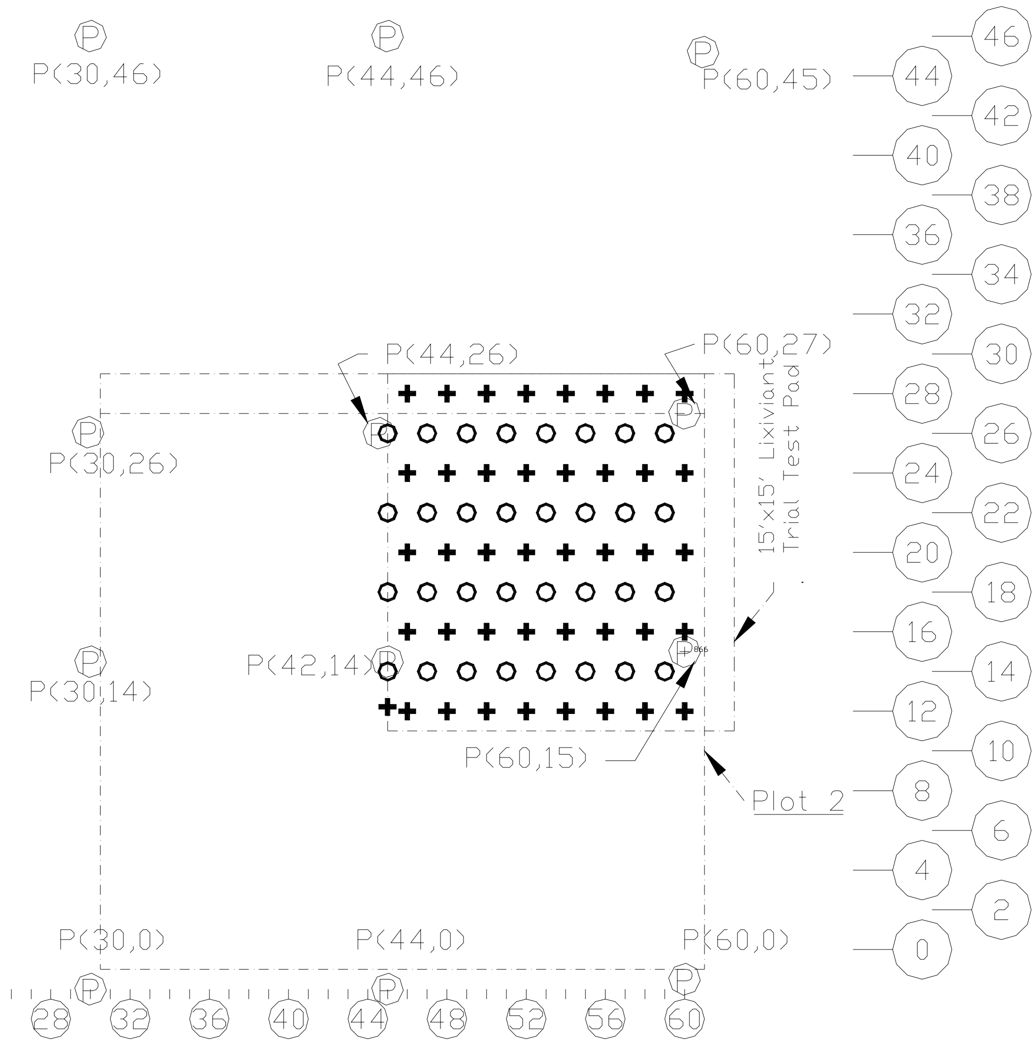


Figure 3: Wide Plot 2 – Pilot Scale Testing Field Layout

Testing Sequence Application:
Sequence #1, Cycle #1: Injection Only Testing – Gravity Feed

Gravity feed testing was conducted from 20 - 22 November 2002. Applied injection rates were initially high, varied between 670 and 2970 gallons/hour (gph), and lasted for a period of up to 1.5 hour. For example, on 20 November, a total of 1872 gallons of potable water were injected, and subsurface water levels were monitored at 15-minute intervals both during the injection phase and for a period of 1 hour after injection was completed. Day 2 operation was set to run for 3.5 hours of injection, then cease injection and observe the mounding dissipation as monitored at thirty-minute intervals for an additional 2 hours. During this testing period, a cumulative of 572 gallons were injected. The initial flow rate of 712 gph for the first hour was reduced to a sustained flow rate between 59 and 136 gph. On the final day of gravity-feed injection testing, a total volume of 800 gallons was injected over a 2.5 hour time period, with corresponding flow rates varying from 180 to 522 gph. Monitoring of water levels was performed at 30-minute intervals for a 6-hour period starting from the initiation of injection.

Results: 20 November 2002

Figure 4 shows the cumulative injected volume, volumetric flow rates, and piezometric elevations, as a function of time, for the 20 November 2002 test. In addition, the graph also presents the relative location of the different subsurface soil stratifications, as well as cesium concentration, as a function of depth. From this figure it is clear that the utilized injection rate spikes water elevation within the first hour of operation, however a large volume of this water was stored within the empty volume of distribution piping headers and manifold lines. Following the first 0.75 hour of injection operation, the flow rates stabilized between 932 to 671 gallons/hr for the remaining hour of operation.

The piezometers located within the 15' x 15' area, specifically P (60,15), P (60,27), and P (44,26) showed increases in the potentiometric (subsurface water) surface of up to six feet. This level was reached in approximately one hour and was maintained during the injection period. Post-injection period levels showed dissipation of the water mounding as P (60,15) lost a head level of 0.5 ft, compared with P (60,27) which dropped approximately 2 ft within a 30-minute period. The P (44,26) location maintained a constant head during the monitoring period which may be due to its down gradient position, reflecting a longer mounding response. In comparison, P(60,45) showed a delayed response which could be expected as it was further down gradient from the injection point (the site gently slopes toward the east, north east direction).

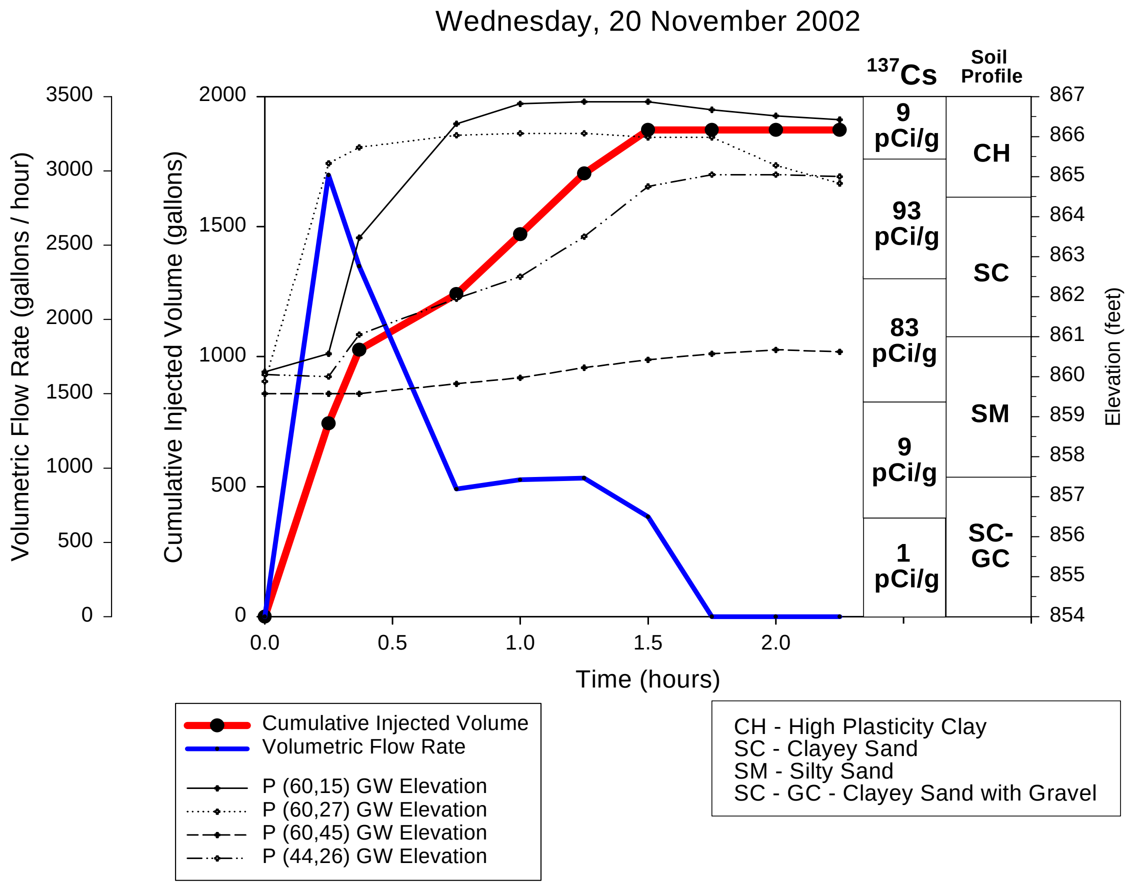


Figure 4: Field Data – 20 November 2002

Some minor surface water ponding was observed and may have been from injection water seeping along the PVW sleeving. The injection operation used tanks #2 and #3. Water head averaged approximately 10ft between the initial tank injection elevation of 874 ft to piezometer head elevation of 860 to 864 ft.

Results: 21 November 2002

The piezometers within the down-gradient zone P (60,27) and P (44,26) continued to reflect rapid response to the injection operation for both the 3.5 hour injection period and 1.5 hour post-injection observation period on day 2 of testing, as is evident by piezometric elevations presented in Figure 5. This figure also presents cumulative volumes and volumetric flow rates; all plotted in conjunction with soil and cesium concentration profiles at the general location.

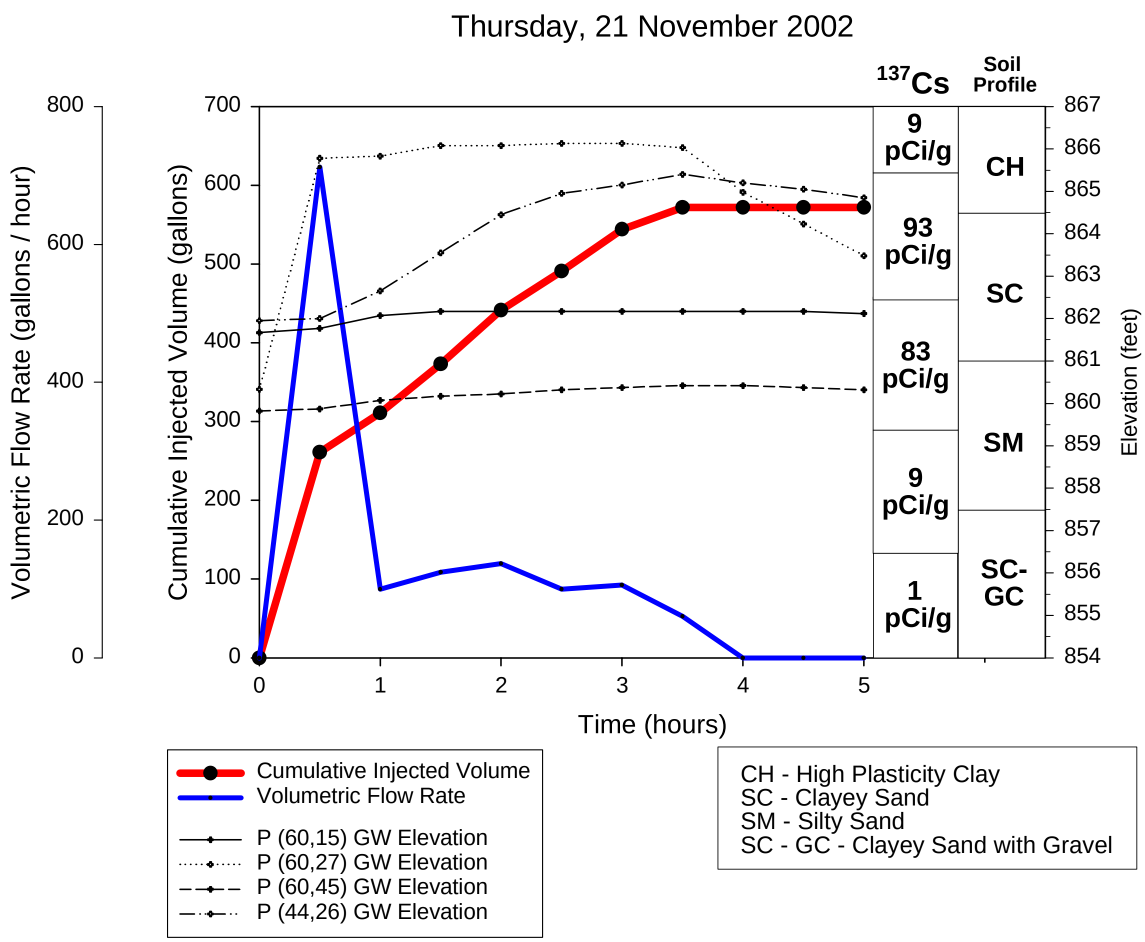


Figure 5: Field Data – 21 November 2002

Results: 22 November 2002

The objective of this day's operation was to continue along the same operational logic as for day 2. In this case, a moderate, and consistent, flow rate was provided over a period of 3.5 hours as shown in Figure 6. Water mounding, during injection and post-injection periods was observed. Results from day 3 are presented in Figure 6, which contains information analogous to previous graphs.

Review of the data indicates that groundwater mounding occurred at a faster rate during injection. For example, Piezometer P (60,27) showed a groundwater head increase from -7.75 ft to -2.05 ft within the first one-hour of operation, where approximately 300 gallons of water was injected. After two and a half hours of injection (814 gallons) the groundwater elevation rose to -1.90 ft below ground level. Post-injection monitoring indicated water head receding to -5.85 ft after two hours. Piezometers P (60,15) and P (44,26) also showed water elevation increases, but with slower rates of decline than that of P (60,27).

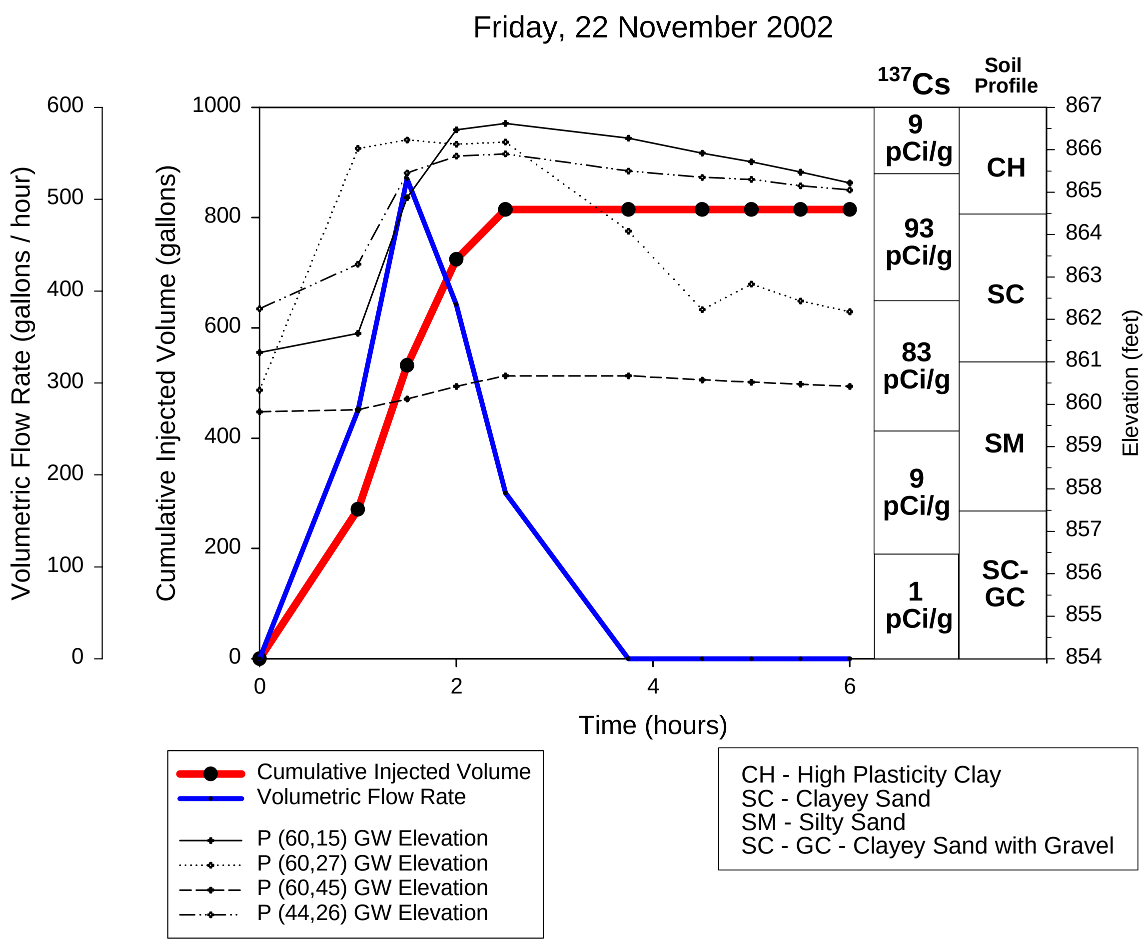


Figure 6: Field Data – 22 November 2002

Sequence #1, Cycle #2: Injection Only Testing – Pressurized (Gradual)

Pressurized injection testing was conducted during the months of January and February 2003. Gradual injection rates selected for this testing cycles are shown in Figure 7 and 8 (21 and 22 January 2003). On 21 January, 750 gallons of potable water were injected over a 4-hours period. Piezometric elevations were monitored on 30 to 60 minute intervals, with readings beginning at the initiation of injection and continuing for an hour after injection completion. Injection flow rates varied from 241 to 301 gallons per hour (gph), with average rates around 250 gph. Flow rates varied from 215 to greater than 560 gph on the 22 of January, when 1123 gallons were injected over a 3-hour time period. Groundwater elevations were again monitored at 30 to 60 minute intervals beginning one hour prior to injection and concluding 3 hours after injection was completed.

Results: 21 January 2003

Results from the gradual pressurized injection testing conducted on 21 January are presented in Figure 7. As with the gravity feed graphs, this figure presents volumetric flow rates, cumulative injected volumes, and piezometer groundwater elevations as a function of run time, along with elevations of cesium concentrations and soil stratification locations. Groundwater elevations show minimal response for piezometers P (60,15), P (44,46) and P (60,45). This may be explained by the pressure head gradual injection being distributed over a wider area but with a minimal impact on increase of piezometric levels. Piezometer P (60,27) displays a relatively delayed response of approximately 4 foot maximum increase in elevation. The delay and magnitude of this response are probably influenced by the down gradient location of this piezometer relative to the injection PVWs.

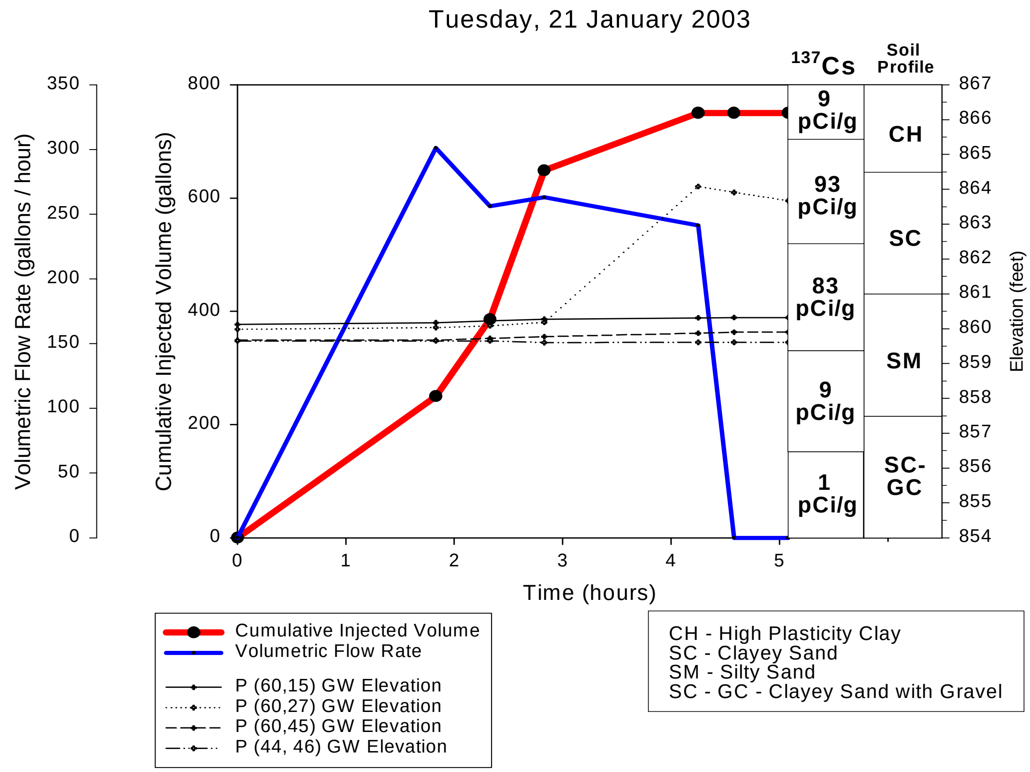


Figure 7: Field Data – 21 January 2003

Results: 22 January 2003

Figure 8 confirms the groundwater response to gradual injection that was seen on 21 January. 22 January data are presented in this figure in the same manner as previous dates. Groundwater response in piezometer P (44,46) again shows slight response to the gradual injection process. P (60,15) and P (60,45) experienced slight rises in groundwater elevation. Comparing injection rates / volumes for both days show that on 22 January relatively higher flow rates, as well as cumulative injected volumes, were delivered. The spike in the injection flow rate is believed to have contributed to the P (60,15) and P (60,45) responses. The relatively delayed response in P (60,27) may further confirm the belief that such response is due to the piezometer down gradient location. It is also noted that gradual injection may lead to quicker distribution of the injected liquid volume over a wider area but with less impact on the rise in elevation.

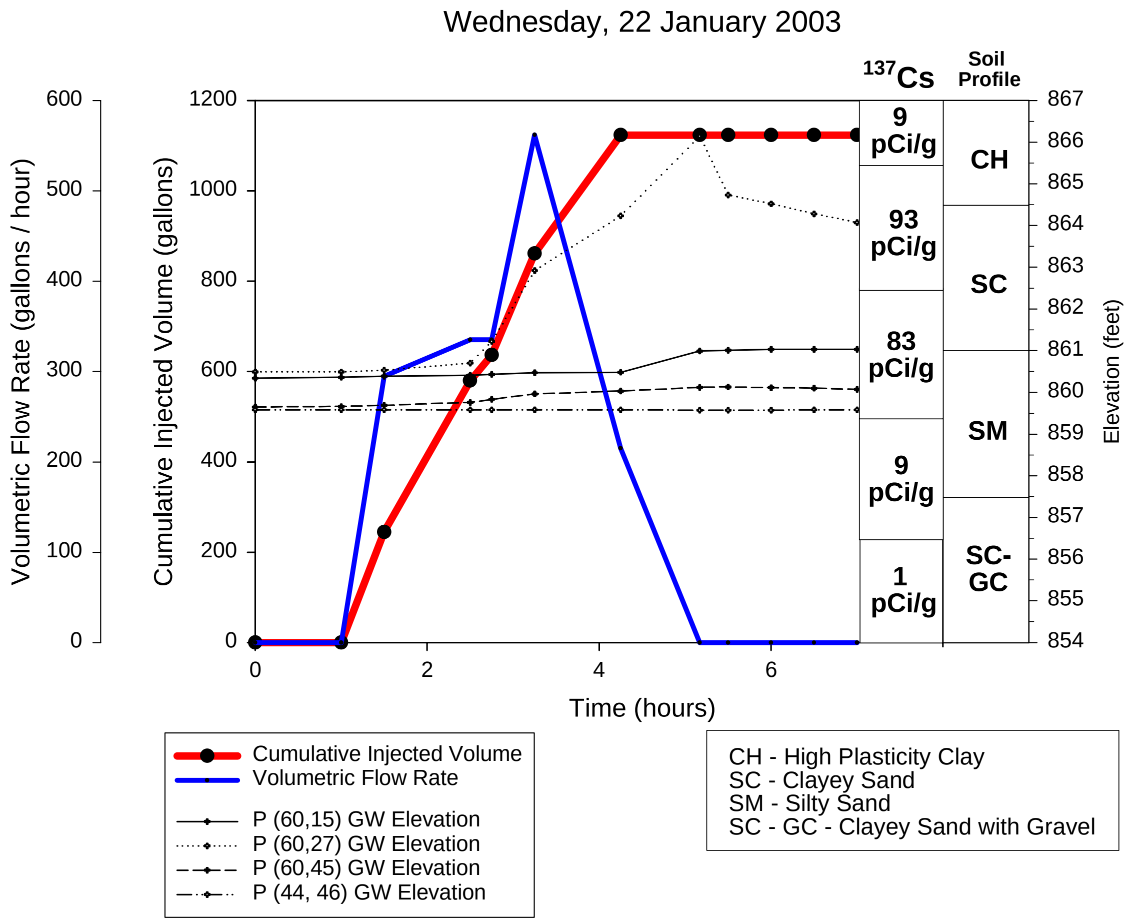


Figure 8: Field Data – 22 January 2003

Cycle #2: Injection Only Testing – Pressurized (Pulsed)

Field testing during the months of January and February 2003 was dedicated to pressurized injection. Pulsed, as opposed to gradual, injection occurred in both a single injection, as well as multiple injection modes. A single injection mode cycle was performed on 3 February with 1200 gallons injected over approximately a 1-hour period, with flow rates of 1100 gph. Piezometric elevations were monitored at 30-minute intervals from 1 hour prior to testing, to 5 hours after testing. On Tuesday, 4 February a multiple pulsed injection was conducted, with 2 injection periods of 1000 gallons each at flow rates between 1212 and 1260 gph. Injection times were 9 AM and 12 PM, and monitoring was conducted at 30 to 60 minute intervals from 8 AM until 3 PM.

Results: 3 February 2003

Pulsed pressurized injection results, in the single injection mode, are presented in Figure 9. Both piezometers P (60,15) and P (30,0) show significant elevation increases under this mode of injection. The immediate rise in P (60,15) correlates to the time of injection in the field. The delay in rise on P (30,0) is likely due to the distance from the point of injection. Lack of response in P (60,27) and P (60,45) during the monitoring time could indicate that injected water did not reach these locations, but possibly flowed towards P (30,0) as substantiated by the delayed rise measured at that point, or possibly frozen water was blocking distribution in the piping system.

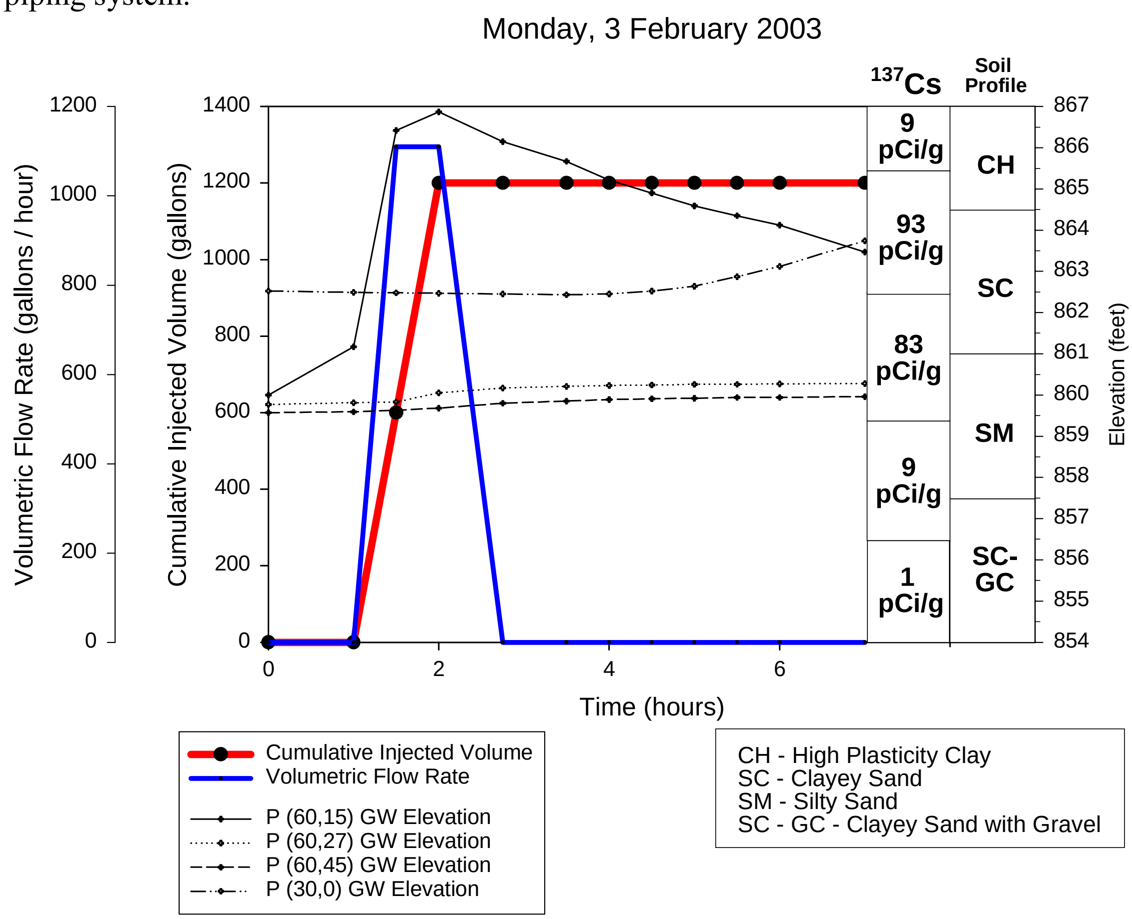


Figure 9: Field Data – 3 February 2003

Results: 4 February 2003

Figure 10 presents results from 4 February testing of a multiple-pulse injection mode. This mode appears to be the most promising in establishing and maintaining a subsurface water rise within the field. Both P (60,15) and P (60,27) show marked increases in elevation due to the initial injection, and additional increases due to the subsequent injections. Down gradient piezometers P (44,46) and P (60,45) begin to experience elevation increases in the later stages of run time. This is in agreement with their downstream location and distance from the point of injection.

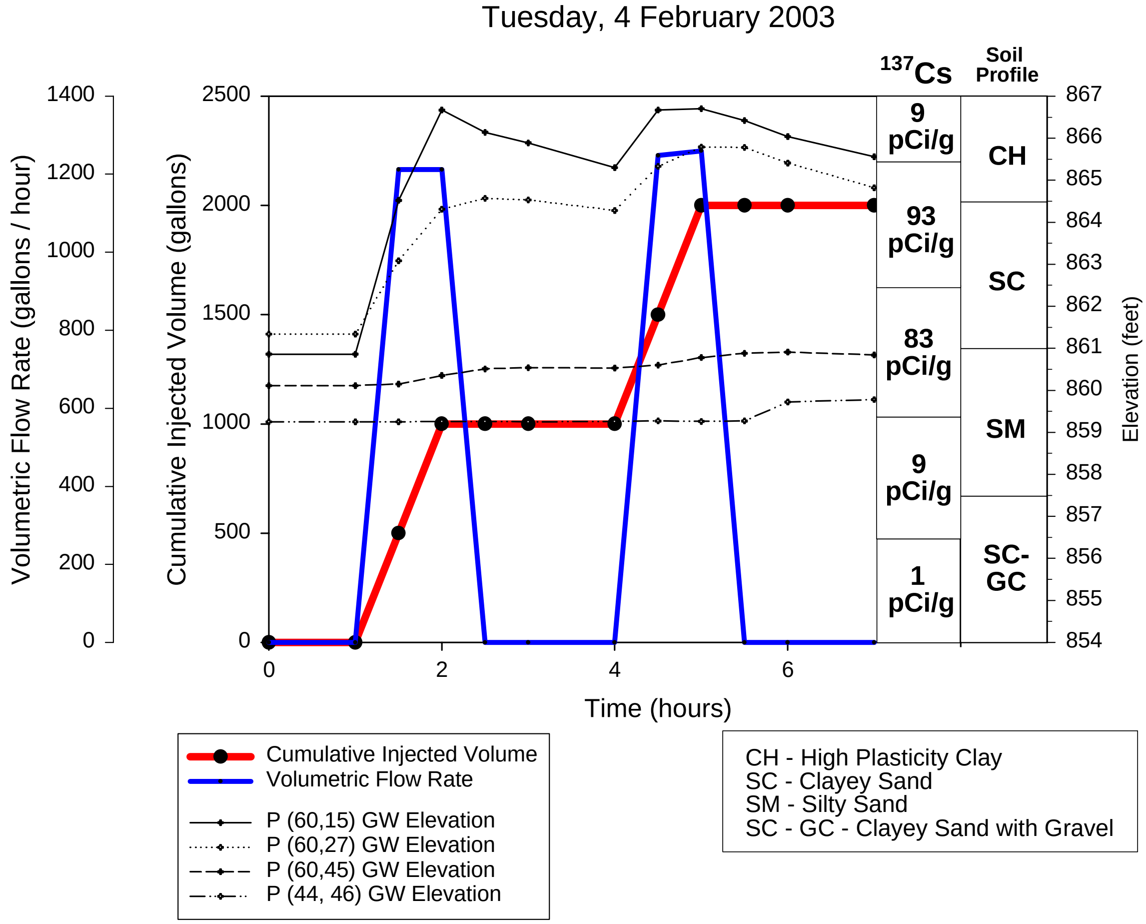


Figure 10: Field Data – 4 February 2003

TESTING SUMMARY

Gravity Feed Injection

During gravity-feed injection tests, a cumulative volume of 3,258 gallons of water was injected into the subsurface. The piezometric responses to this injection were observed to be mostly consistent. The piezometers closest to the injection points showed the most rapid mounding and most response to injection flow, compared to piezometers located down and up gradient, which showed either mounding post-injection, or no mounding effect, respectively.

The mounding delay was at most 30 minutes and remained reasonably steady during the injection period. However, once the injection process ended, dissipation time of the created mound was within two to four-hours, and usually a decline to pre-injection piezometric levels was observed over a period of 24 hours. This is expected, however, since for the 3-day run time, the cumulative pore volume is less than 15% of that required to raise the test area subsurface water elevation by 1 ft. Such mass balance does not account for leakage through boundaries of the subject subsurface profile. It should also be mentioned that the filter bed area does not act as a “bowl”. This is based on limited field data which indicated that after injection of approximately 12,000 gallons of water, no discernable permanent increases in the groundwater table was observed.

Based on field data from 21 and 22 Jan, it appears that gradual injection process resulted in a water mounding effect which was noticeable in the down-gradient piezometers. Specifically, on 22 Jan, the 1100+ gal of water injected resulted in a groundwater mound which extended approximately 30 ft down-gradient of the test pad area and 15 ft up-gradient over four hour injection period with an injection rate of approximately 5 gpm. The maximum mounding front was at approximately 2 to 3 hrs after completion of the injection cycle. As shown in Figure 11, approximately 1-2 feet of rise in subsurface water elevation was recorded with the gradual injection model. The zone impacted with injection was nearly within the area of injection (15 ft x 15 ft).

Pressurized Injection

Given the need in future phase to raise the subsurface water elevation by approximately 6 ft in order to expose the site soils to the Lixiviant (as proposed by PNNL), it seems that pulsed injection is the recommended mode of operation. Data shown Figure 10 confirm such a finding. Figure 12 shows the rise in subsurface piezometric level for a piezometer located at the southeast corner of the test pad. For the case of pulsed-injection where 20 gpm was used over a period of typically one hour, a significant rise in the water table was recorded. In comparison, a gradual rise in the subsurface water table was observed with the gradual injection over a period of approximately 5 hours. However, pulsed injection shows a shorter mounding time when compared to gravity feed injection.

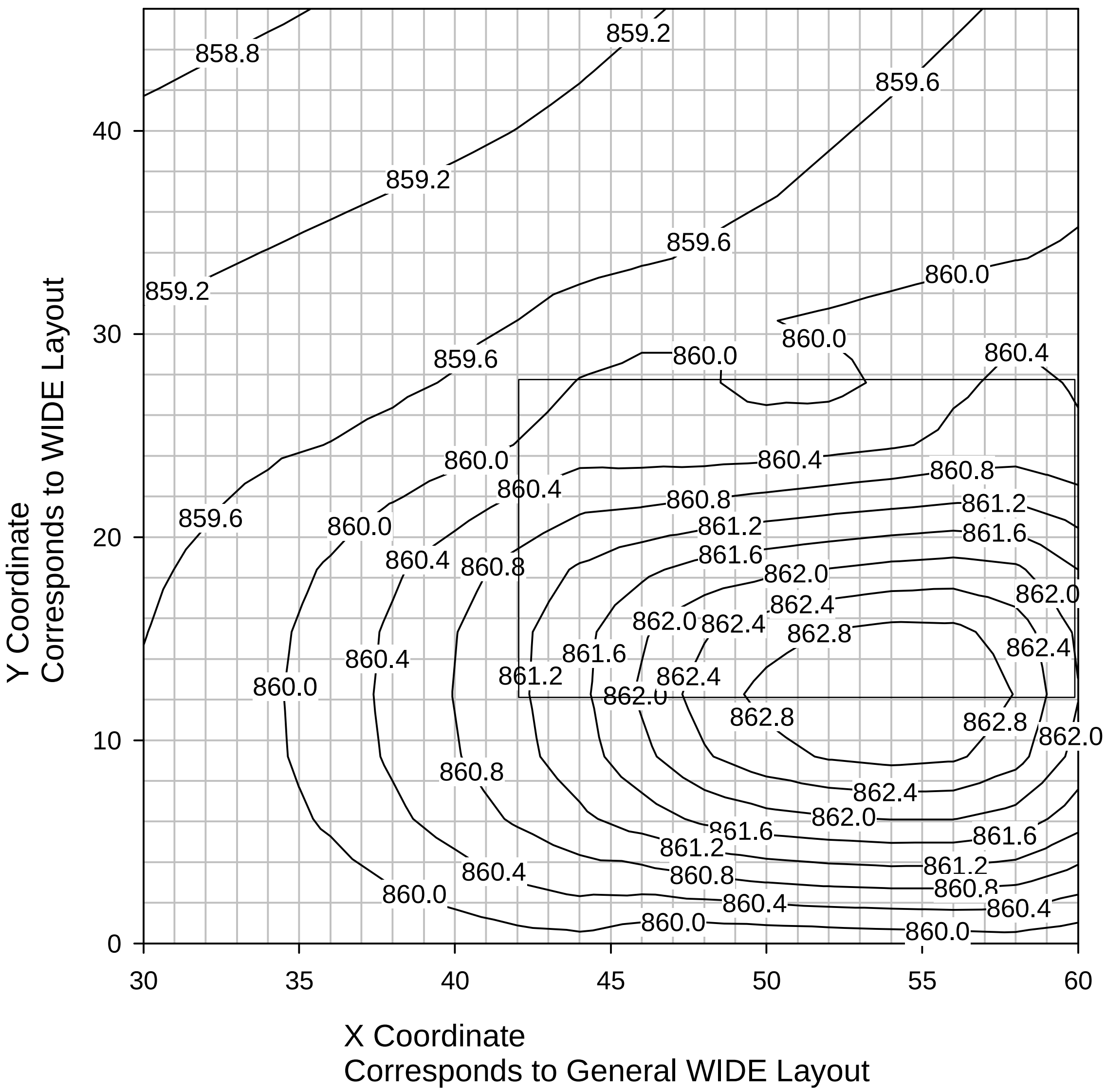


Figure 11: Piezometric Contours for Injection over the 15 ft x 15 ft Test Pad (Alternate Rows)

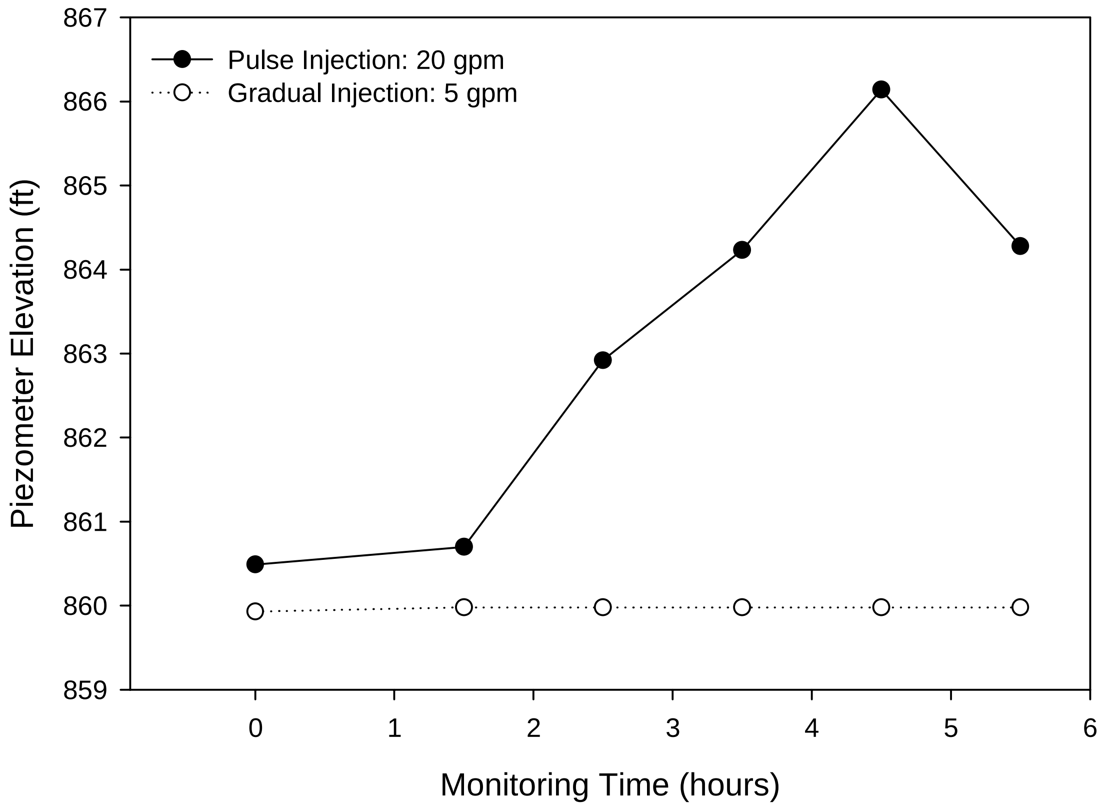


Figure 12: Effect of Injection Mode on Piezometric Levels

The results from the pulse injection test (Monday, 3 Feb 2003) yielded data trends indicating groundwater mound dissipation rates. Injection operations consisted of high flow rates over short time periods at rates of 1200 gallons/hr. For the first single injection event, the mounding response was concurrent with injection and the decline in groundwater occurred at a rate of 0.67 ft/hr over a four-hour monitoring period. Full dissipation of the mound occurred within 24 hours. An important finding from this test was that the rise in the subsurface water level reached a peak elevation of 866.87 ft from initial level of 860.0 ft. This corresponds to over a six foot rise in elevation within one hour period of injection. Mounding dissipation rates for this case ranged from 0.57 to 0.69 ft/hr.

During the multiple injection cycle, conducted on 4 February, a total of 2,000 gallons of water was injected at 1,000 gallon volumes over one-hour interval staggered two hours apart (see Figure 10). Two regional piezometers within the pilot field area, P (60,15) and P (60,27), yielded similar responses. For the first injection pulse of 1,000 gallons, the inflow rate was 20 gpm. The piezometric response at P (60,15) showed an immediate rise of approximately 6 feet (860.86 ft to 866.67 ft) within the first hour of injection, then a decline at a rate of 0.69 ft/hr. The second injection pulse, occurring three hours after the first injection, yielded a rise in the subsurface water of approximately 1.4 feet (from an initial elevation of 865.3 ft to 866.67 ft.) The mound decline occurred at a similar rate of 0.57 ft/hr. The pulse response for piezometer P(60,15) was similar to piezometer P(60,27) in that a rapid mound developed, then a steady decline, followed with another increase in elevation, and a subsequent tapering of the elevation at a rate of approximately 0.64 ft/hr.

Injection Mode Comparison

A comparison of the various types of injection modes is presented in Table 1. This table demonstrates the value of pulsed pumping over the other methods utilized in maintaining saturation of the subsurface. Maximum mounding occurs within 3-hour in the gravity feed injection; however, the mounding dissipation rate is relatively large with saturation time on the order of 3 hours. Gradual pumping injection has the longest time to achieve mounding. The mounding magnitude is low, but with the slower dissipation, saturation maybe maintained for a longer period of time. Pulsed pumping exhibited approximately one-third the dissipation rate of gravity injection and almost half the rate of gradual pumping injection. This comparatively low declination rate, combined with a modest time for mounding to occur, translates into a best-case saturation scenario for the subsurface under the described testing and site conditions.

Table 1: Comparison of Injection Mode Results

Injection Mode	Volume Injected (gallons)	Injection Time (hours)	Max Mounding Time (hours)	Dissipation Rate (ft/hr)
Cycle 1 (gravity feed) (22 November)	815 gallons	2.5 hours	3 hours	1.98 ft/hr
Cycle 2 (gradual pumping) (22 January)	1123 gallons	4.25 hours	5 hours	1.14 ft/hr
Cycle 2 (pulsed pumping) (4 February)	2000 gallons	2 1-hour increments (spaced by 3 hours start to start)	4 hours	0.64 ft/hr

Air Curtain Testing

Application of a positive pressure air injection in the alternating rows to the liquid injection operation within the pilot area was conducted in order to produce an air curtain effect. The air curtain testing objective was to evaluate increased water residence time within the PVWs zone of influence. The positive air pressure was evaluated in two stages. Stage 1 involved air pressure application concurrent with water injection, while Stage 2 used a preset delay-time interval between water injection and air pressure application. The piezometers were monitored for indications of reduced mounding dissipation with time.

The first test involved the injection of water (2,000 gallons) in two separate injection cycles spaced three hours. An air pressure of 10 psi was applied to the adjoining PVW piping concurrent with water injection. Results of this testing showed little response recorded in the piezometers. The second air pressure test involved the injection of water (2,000 gallons) but the air pressure was applied one hour after the water injection. As in the first test, the air pressure effect showed no significant results in either developing an initial water mound or maintaining the groundwater regionally.

Evaluation of the data tended to indicate that the tests were inconclusive. The magnitude of the air pressure may be too high in the case causing depression of the water surface. It has been determined that icing and construction assembly factors appear to also have a controlling effect over the air curtain test. The ground and some surface piping were frozen and the applied air pressure was observed to have displaced the bentonite packing around several of the PVWs, thus not permitting a pressure head to develop.

GROUNDWATER MODELING

Computer modeling was utilized in the analysis of the WIDE system performance. The main objective of this modeling phase was to discern time required to obtain saturation of the subsurface profile. The modeling was intended to aide in the prediction of effectiveness and time dependence of the remediation process of Cesium in the subsurface environment. This modeling is a necessary step in order to generate initial-condition data for contaminant transport modeling to be performed during Phase III. Modeling has been performed on the injection – only mode, considering only water and existing site characteristics.

Model Description

The computer model used is Seep/W Version 5 from Geo-Slope International. This 2-D finite-element program allows for modeling of both saturated and unsaturated conditions (and interface) to determine water movement, hydraulic head, and pore water pressure distribution within the subsurface environment. Modeling was conducted under two different modes of analysis. The first considers the subsurface elevation profile in an axi-symmetric analysis mode. The second considers the plan view, in a plain strain model, for analysis.

Model: Axi-symmetric Analysis

In order to assess the effectiveness of the model developed for the analysis domain, initial numerical testing was performed on a limited set of parameters to establish basic modeling performance. These limited parameters allow for model testing, without the encumbrance of significant input time if complications arose during the processing stages. Once the initial model testing had been completed, it was possible to progress to a more refined set of data for use in systematic analysis. In this case, the subsurface profile was enhanced to include major soil stratifications, existing water table, and installed and utilized PVWs.

Site Parameters

The first step in the modeling effort was to establish subsurface conditions representative of the in situ conditions. To this end, field profile including soil stratification, subsurface water table and PVWs spacing were synthesized from design specifications and Phase I soil report. The water table was set at a depth of ten feet below ground surface, as approximately detected in the field.

Material properties required for analysis for each of the relevant soil layers include grain size distribution curves, volumetric water content functions, hydraulic conductivity functions, and permeability ratios. From previous soil characterization report (Phase I), it was determined that four main soil layers exist in the subsurface environment. The first is a low permeability clay layer that extends roughly 2.5 feet below the ground surface. The second is a clayey sand (SC), present from 2.5 feet to 6 feet below ground surface. Next is a silty sand (SM), located from 6 to

9.5 feet below ground surface, and the final layer is a clayey sand with gravel (SC-GC) extending from 9.5 to 13 feet below ground surface.

Volumetric water content functions are important for modeling unsaturated conditions, since water content variations (or the amount of saturation) affect hydraulic conductivity values. This function is determined by a soil – water potential test, which compares the change in the volumetric water content as a function of increasing applied vacuum pressure. Hydraulic conductivity functions are also important for unsaturated conditions, since the conductivity rate is dependent on the degree of saturation. Both the volumetric water content and hydraulic conductivity functions are analyzed for the range of cases representing the completely dry condition to the completely saturated condition. In the model, soils below the water table do not need to be defined separately from those above the water table. The program has the capability to apply the saturated parameters to soils below the water table, allowing for the transformation of unsaturated to saturated conditions and vice versa. Permeability ratios are used to describe vertical and horizontal hydraulic conductivities. Since many soils exhibit significant anisotropy, this ratio allows for taking such effect into account in modeling analysis.

Figure 13 illustrates the idealized site layers in the model. The top 2.5 feet is the clay cap. The PVWs at this depth are considered to be sealed due to the impermeable membrane sleeve, which is designed to prevent fluid transfer from well to soil or vice-versa. The additional soil layers are labeled, with shading variations illustrating depths of stratification changes. The water table is shown as a dashed line at the corresponding depth. Please notes that the entire profile was shifted 0.5 feet in both the x and y directions in order to prevent the overlap from the axes tick marks, but this does not affect the analysis.

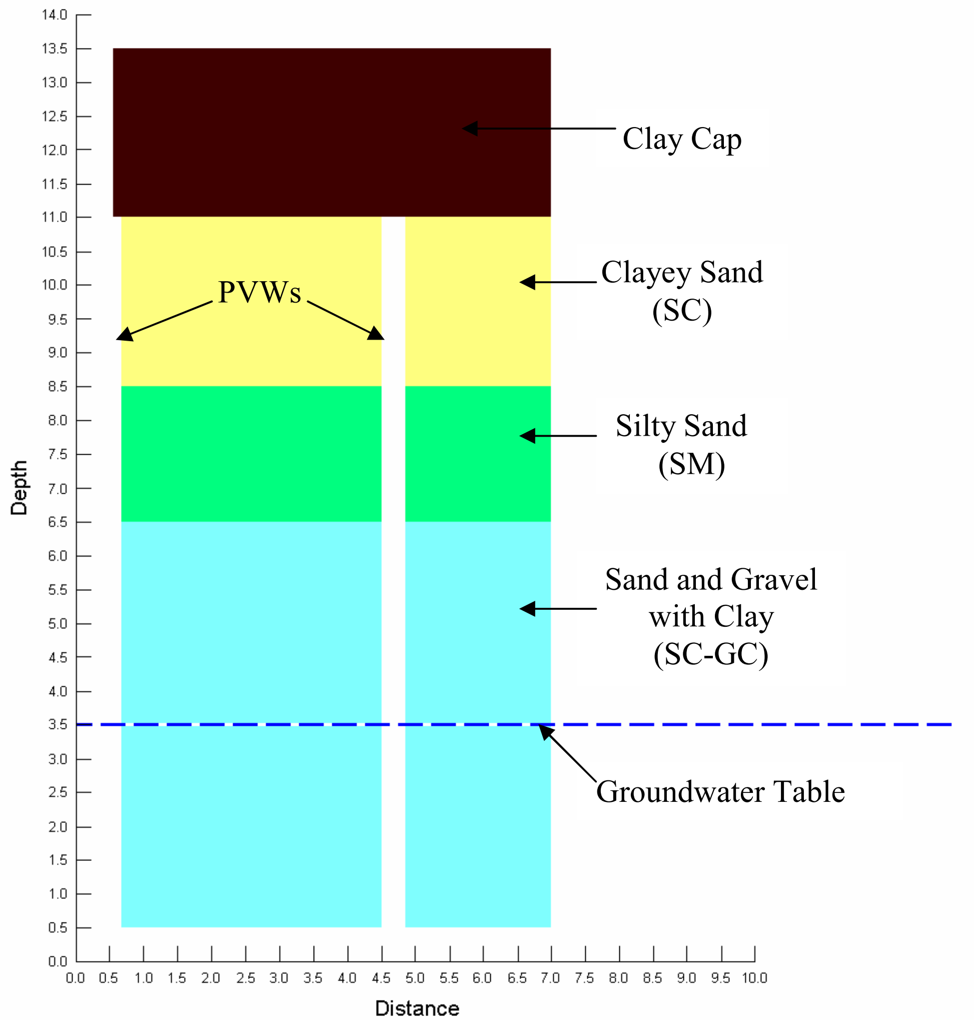


Figure 13: General Site Parameters for Axi-Symmetric Analysis

Modeling Parameters

Once the subsurface profile is idealized, the domain is discretized, using a mesh, for the finite-element analysis. It is important to create a mesh that is neither too coarse (which can cause complications with oversimplification of the system) or too fine (which can result in excessively long run times). The mesh established for the site consisted of 1585 nodes and 1470 elements (quadrilaterals or triangles). This allowed for a balance between accuracy and timeliness. Figure 14 illustrates the established mesh, soil layers, PVWs locations, and water table location, as well as all boundary conditions imposed on the system. The solid triangles at the top and bottom represent "no flow" boundary conditions, while the solid triangles elsewhere represent a unit flux across the length of the elements bound by those nodes.

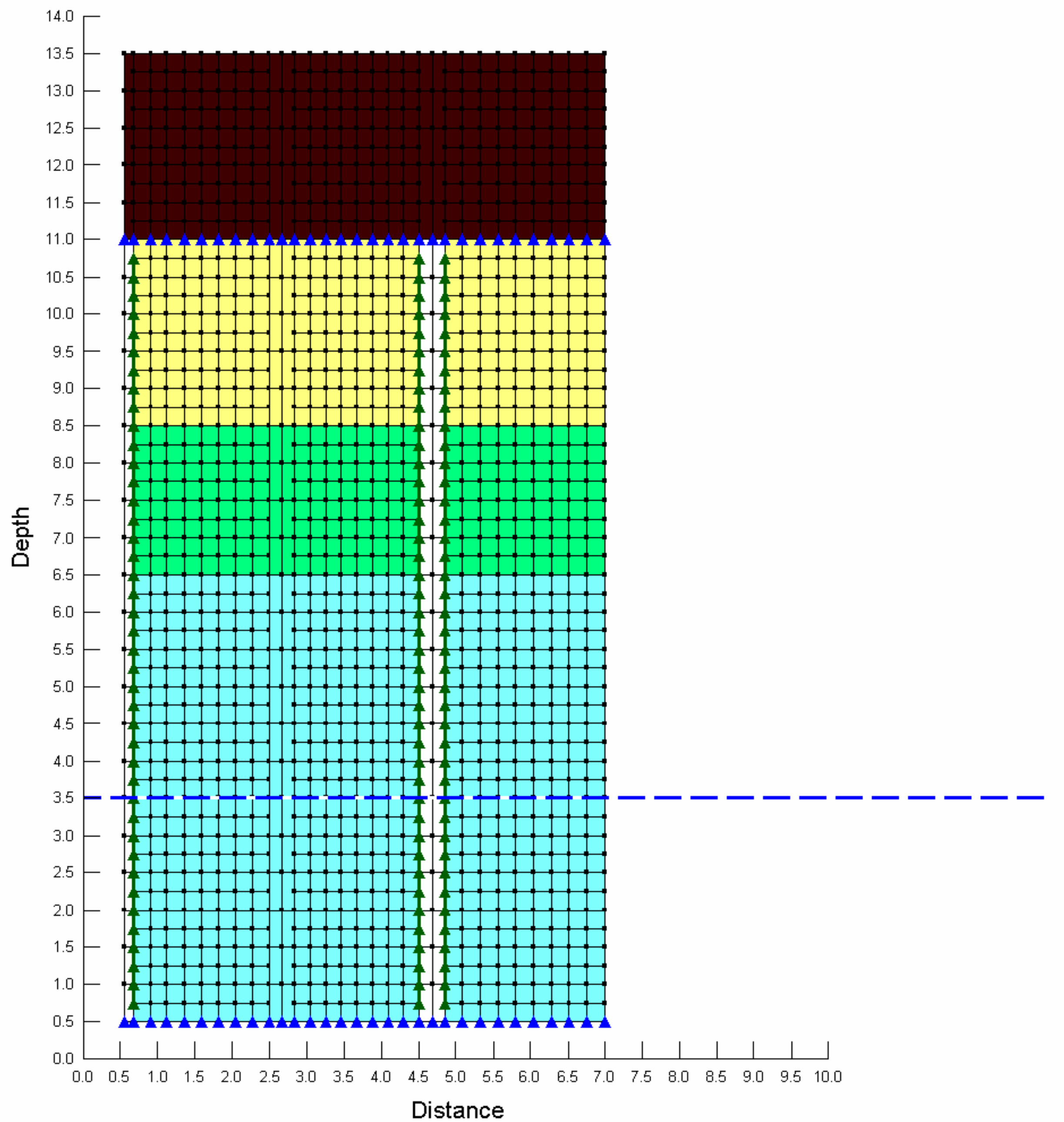


Figure 14: General Modeling Parameters for Axi-Symmetric Analysis

Since the program is run in axi-symmetric mode, the model considers a 1 radian-thick slice of a circular section. However, each element possesses a thickness of 6.283 (2Πrad) and thus, during analysis, the entire circular area is considered, providing results that are representative of 3-dimensional field domain. For this type of analysis, the program considers the y-axis (or the left side of the illustrations) as the rotation point, and the x-axis as the diameter. Because of the axial symmetry, certain modifications to actual field conditions were necessary. The modifications were mainly associated with the well spacing, and subsequent injection volumes (rates). Field dimensions of the initial test plot consider area of 15 ft x 15 ft. Within this area, sequence 1, cycle 2 testing involved injection using 28 PVWs. Modeling will consider a well at the center of this test plot as the rotation point for analysis. In doing this, a circle can be constructed with a diameter equal to 7.5 feet, and will encapsulate the entire test pad. Once this is complete, it is necessary to transform the pad into an axi-symmetric profile view. To accomplish this step, focus was placed mainly on obtaining corresponding injection volumes between field and model. Flow rate from the 28 PVWs was correlated to flow rates from a central well and a "ring" well (created by rotating a single injection well 2Πrad during analysis). This "ring well" is placed 4 feet from the center and is 4 inches thick. Total area of this "ring well" is calculated using the following equation:

$$\text{Area} = 0.7854\,(d_{outer}^{2} - d_{inner}^{2})$$

where: d_{outer} is the diameter of the outside portion (4.25 ft)
d_{inner} is the diameter of the inner portion (4.0 ft)

Utilizing this equation, the total area per foot of depth is 1.62 ft^2. Total area of the wells in the field (per foot of depth) is well width (4 inches) multiplied by well thickness (0.16 inches) times the 28 PVWs in operation, for a total of 0.124 ft^2. Thus, any flow rate utilized in the field would have to be increased in the modeling by a ratio corresponding to the difference in well injection areas.

Transient Analysis

After refining both of the site-discretized domain and modeling parameters, transient analysis was conducted based on an injection-only mode. Trials were run utilizing a field injection rate of 1 cc/sec (3.05 ft^3/day), which corresponds to a modeling injection rate of 39.9 ft^3/day (this will result in the same total volume injected per hour for both the model and field). Figure 15 graphs the water table contour variation with time for a 24-hour period of constant run time. Data labels correspond to the total number of hours the system has been in operation. Figure 16 graphs the water table contour variations, with time, corresponding to initial, one, five, ten, and twenty-five-day time periods.

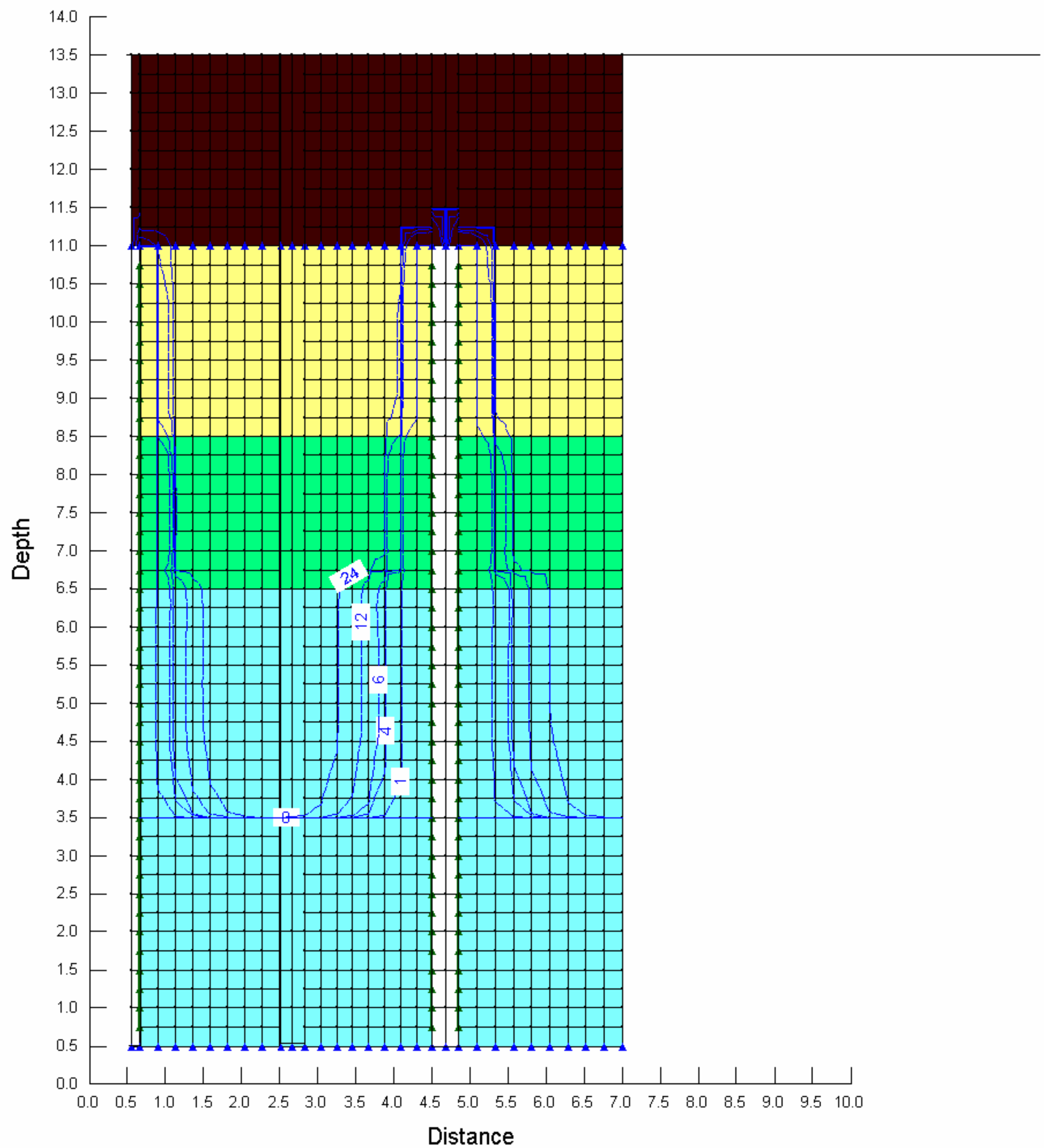


Figure 15: Axi-Symmetric Transient Analysis for continuous run 24-hour period (labels indicate hour)

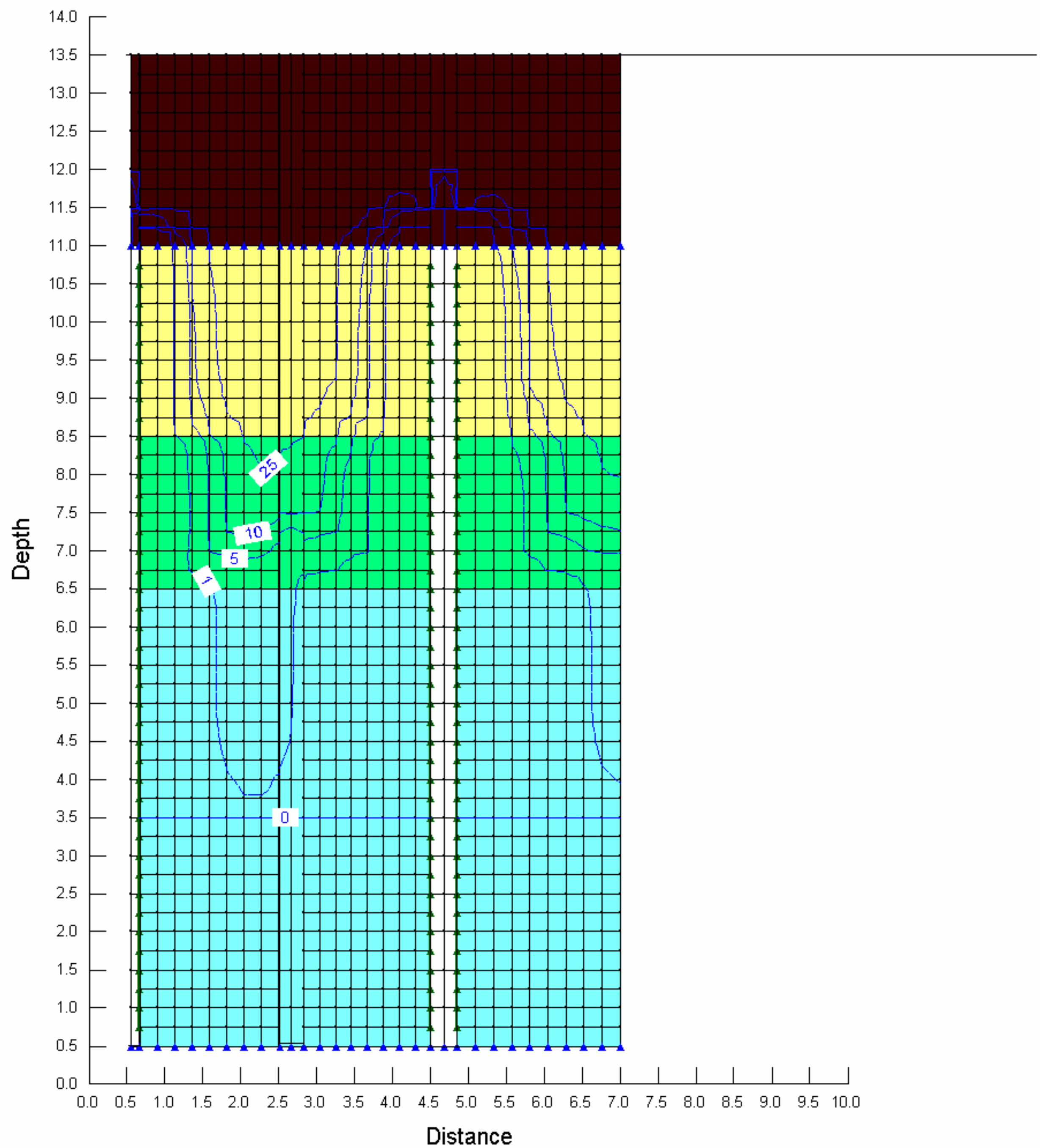


Figure 16: Axi-Symmetric Transient Analysis for continuos run 25 day period (labels indicate days)

One of the important issues to note is the presence of preferential flow regime (increased flow in certain layers over other layers). With the presence of four subsurface soil layers possessing a myriad of soil properties, the occurrence of preferential flow is very likely. The obvious location for preferential flow is in the silty sand layer (from 6 - 9.5 feet below ground surface). Due to the presence of silt, instead of clay, the hydraulic conductivity of this layer is 2-3 orders of magnitude greater than that of the bounding layers. The higher hydraulic conductivity corresponds to increase in flow volume across the layer. The result of this preferential flow is an increase in the amount of time necessary to obtain a saturation of the entire subsurface to the desired level. From modeling, it appears that to completely and permanently saturate the system to a depth of 2.5 feet below ground surface, 25 days of run time is necessary.

Model Testing - Plan View Analysis

In addition to the axi-symmetric analyses, plan view modeling analysis was employed in order to determine distribution of the injected liquid in horizontal plane orientation.

Site Parameters

As with axi-symmetric analysis, the first step was to establish subsurface conditions representative of the domain to be modeled. Thus, piezometers and PVW locations and spacing within the 15' x 15' test plot were identified, as well as piezometer locations within the rest of the 30' x 30' Plot 2. However, due to modeling limitations, it is possible to conduct horizontal plane analysis only on homogeneous layers of a single thickness (thickness in the z-direction is assumed unity). For this part of model simulation, focus was placed on the 3.5-foot-thick silty sand (SM) layer located at a depth of 6 - 9.5 feet below ground surface. This layer was chosen due to its proximity to the groundwater table and the relatively high levels of cesium contamination present. The analysis employed material properties for the SM soil type including grain size distribution curves, volumetric water content functions, hydraulic conductivity functions, and permeability ratios. Properties for this soil layer correspond to properties used in axi-symmetric analysis, and were obtained in the manner described in the site parameters part of axi-symmetric analysis model testing section of this report.

Complications aroused from the fact that the in situ level of water table is below the SM soil layer, as well as the fact that no water table can be drawn in a simplified straight line form when using the in-plane analysis mode. In order to obtain initial conditions (as illustrated by the dashed line representing the initial groundwater table in axi-symmetric analysis) steady-state analysis is first run. This type of analysis considers long ranging effects of conditions and presents results that are unaffected by additional time increments. These steady state conditions were determined from an analysis incorporating a comparison of the elevations of the initial groundwater table versus the elevation of the top of the subsurface soil layer under consideration. Groundwater readings from the nine piezometers within the 30' x 30' Plot 2 layout were employed and entered as constant head boundaries in the steady state analysis. Results of this analysis are presented in Figure 17. Numerical values on the figure correspond to total head elevations as taken from the top of the SM soil layer (considered to be datum for this analysis). These results illustrate the hydraulic gradient that is present across the site and serve as an initiation point for transient analysis testing.

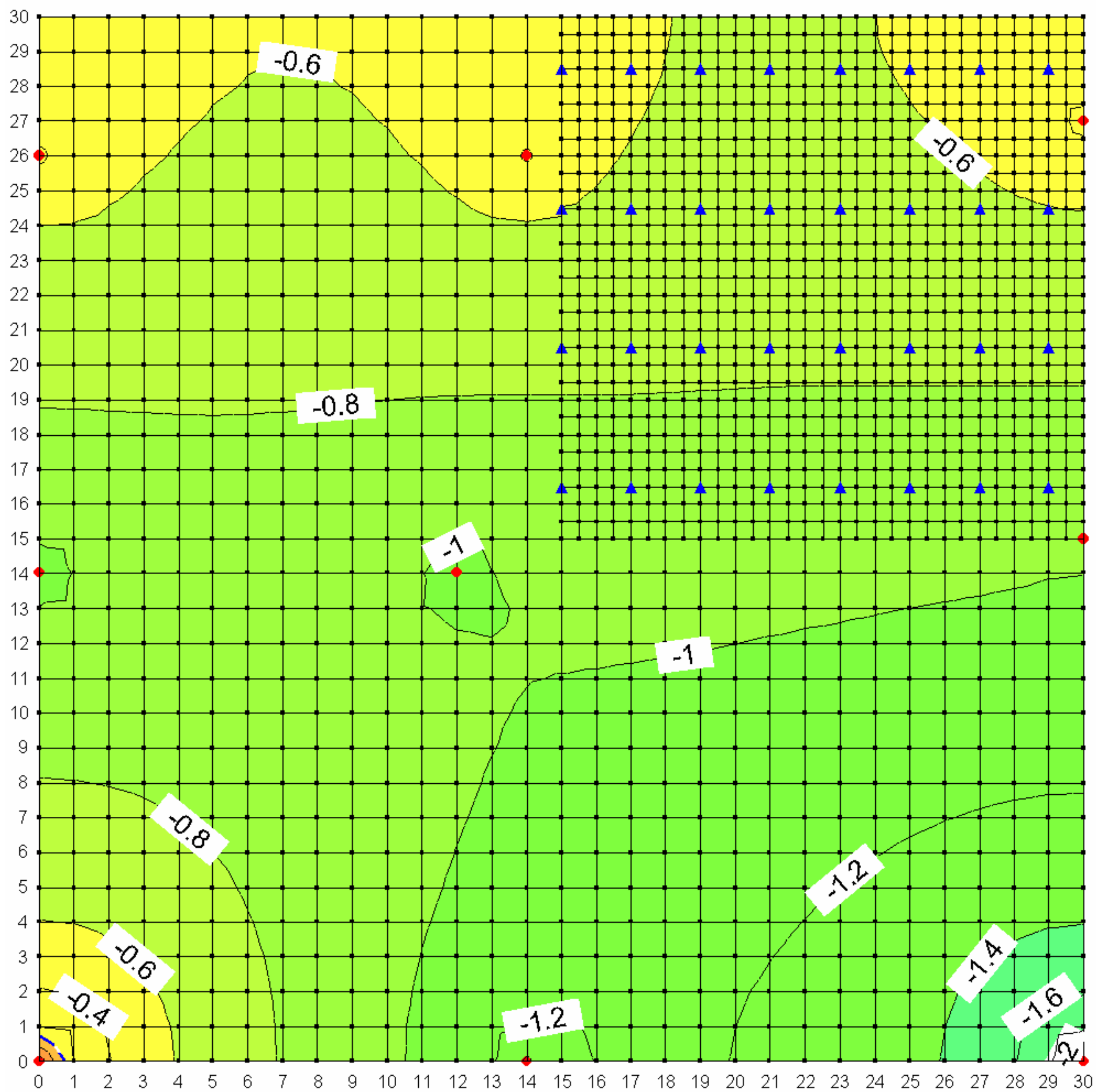


Figure 17: Initial Groundwater Elevations from Steady-State Analysis of SM Layer

Modeling Parameters

The mesh established for use in the horizontal plane analyses consisted of 1666 nodes and 1575 elements, and was designed to maximize both accuracy and timeliness. Figure 18 illustrates the established mesh, well and piezometer locations, as well as any boundary conditions imposed on the system. Each piezometer is represented by a solid circle, while the PVWs are represented by solid triangles. No boundary conditions are used in this analysis, as flow is allowed to escape from the edges (i.e. flow in the field is not confined to the 30' x 30' layout). Mesh elements are more precise within the 15' x 15' test pad layout, and coarser in the remaining portion of the Plot 2 layout. This is to focus analysis on the test pad layout itself, rather than on extraneous locations. Layer thickness was set at 3.5 feet, and the x and y-axes on all figures correspond to x and y directions in the field. The x-axis model "0 value" equates to a field value of 30, while the y-axis model "0 value" equates to a field value of 0. This means that the piezometer with the lowest co-ordinates in both directions has a coordinate of (0,0), which corresponds to P (30,0) in the field.

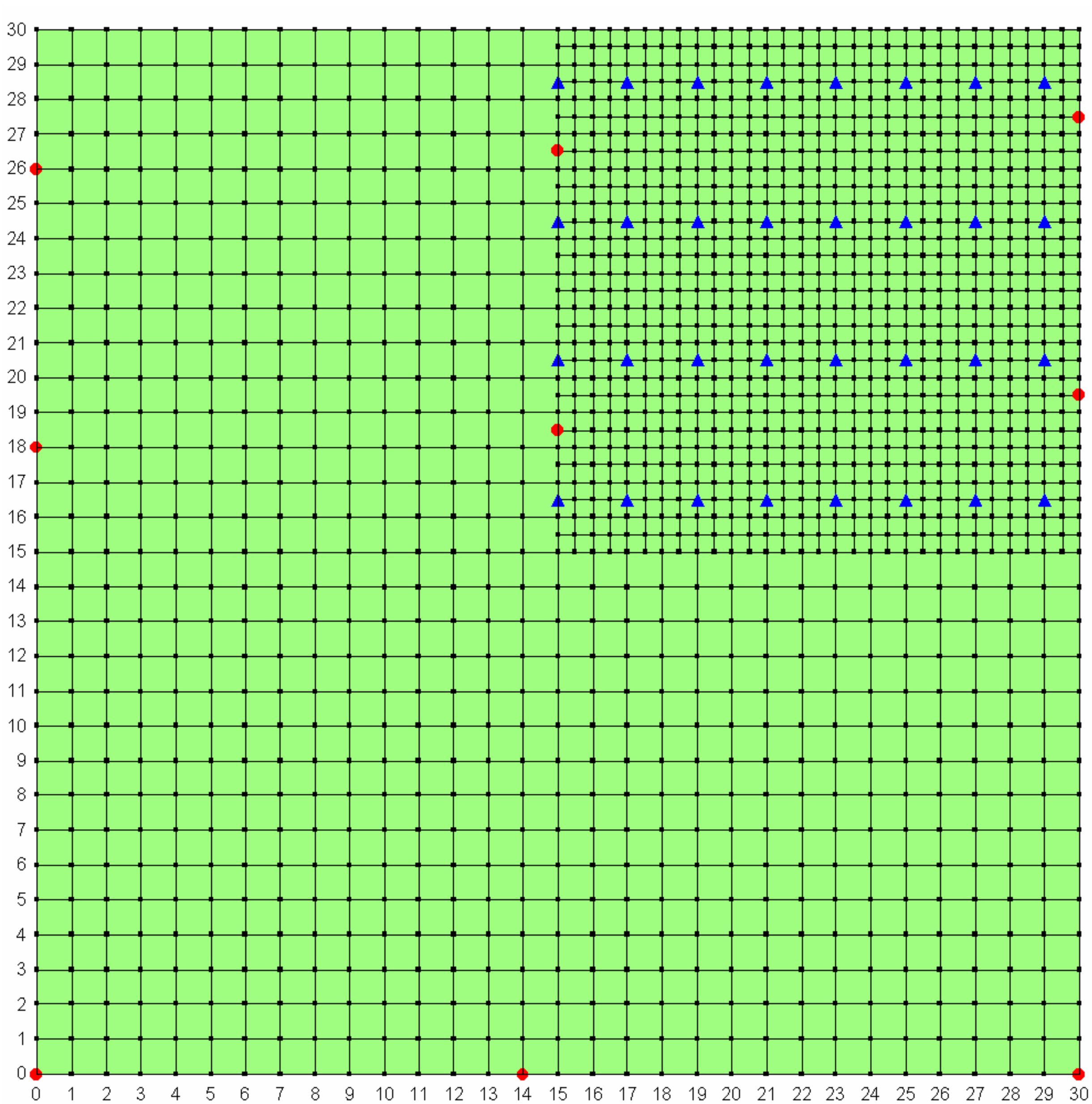


Figure 18: General Modeling Parameters for Plan View Analysis of SM Layer

Transient Analysis

Transient analysis was completed in a number of stages. The first run employed the steady state analyses results as initial head conditions and progressed with injection for a one-hour time period. During this hour, injections were made in each of the 28 PVWs and corresponded to a total injection volume of 1200 gallons over the one-hour time period. The second run sequence was to monitor the dissipation of the injected fluid as a function of time during a period of no injection. Results from the first run show high pressure heads within a 0.5 foot radius of the PVW injection points. This corresponds with field results where the presence of water near the ground surface was confirmed during injection phases. Results also show a general rise in the groundwater table within the test pad layout as presented in Figure 19. This rise varies from 0-5 feet across the site and corresponds to piezometer readings in the field. Results from a second run show a dissipation trend in the subsurface water levels with time during the post injection period. The end result is the return of the water table to pre-injection levels.

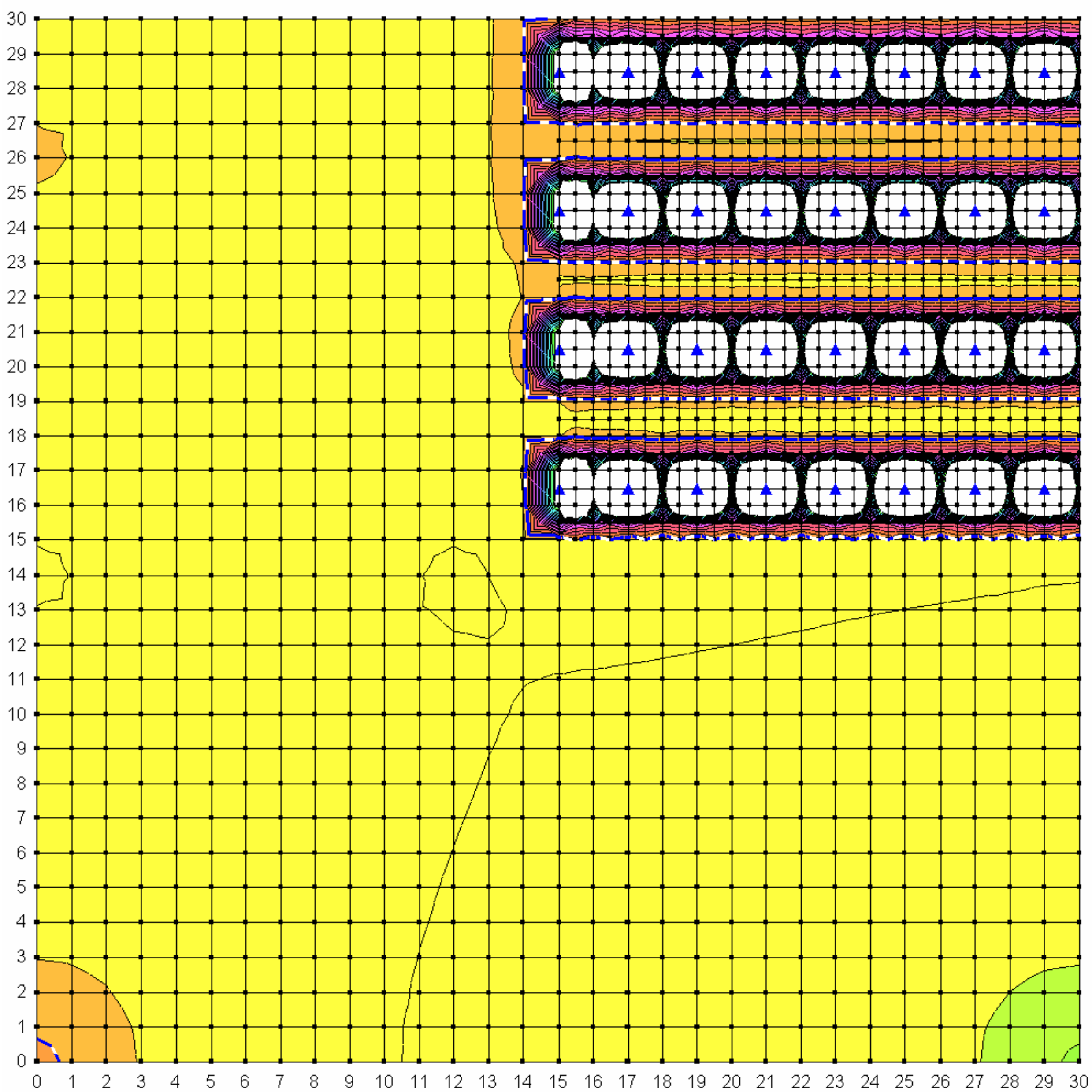


Figure 19: Groundwater Elevations Post-Injection in SM Layer

Modeling Summary

Two different modeling scenarios have been established, one that considers a profile view of the site subsurface and a second that considers the plan view of the site. The profile view is modeled as an axi-symmetric analysis rotated around a central well and modeling additional wells as a ring well surrounding this central well. This modeling step is a necessary step in order to generate initial condition data for the contaminant transport modeling to be performed during Phase III.

Some deviations from actual field conditions were necessary in order to perform axi-symmetric analysis. Corrections were made to the well cross-sectional areas to correlate injection rates between field and modeling as closely as possible. Results from the axi-symmetric analysis illustrated the preferential flow that may occur in the subsurface. This flow bias is based on relative permeabilities of the different layers; increased flow volumes are present in those layers with higher hydraulic conductivities, while those layers with low hydraulic conductivities experience reduced levels of volumetric input.

Due to the necessity of homogeneity of the soil profile in horizontal plane orientation type of analysis, silty sand (SM) layer was chosen as a focus layer. This choice was based on layer proximity to the groundwater table, as well as Cesium concentrations in excess of required levels. Prior to injection runs, initial head conditions were established based on steady state analysis using piezometric data from initial groundwater monitoring measured the morning of 3 February prior to WIDE system operation. Correlation between model and field data shows similar gradient trends for steady state conditions. Injection testing was then performed with a 1200 gallon injection over a 1 hour time period. Results were monitored for a period of 24 hours after injection and showed a groundwater rise and subsequent return to pre-testing levels after a period of no injection. This injection schedule corresponds to the injection performed on 3 February, and comparisons can be drawn between model and field data. Comparisons were performed on those piezometers within the 15' x 15' test pad layout. Table 2 summarizes the total change in subsurface water elevation for each of the piezometers from both model and field testing over the 4 hour post-injection period.

Table 2: Subsurface water elevation changes by piezometer for field and modeling data

Piezometer	Field Data (feet) (3 Feb 2003)	Modeling Data (feet)
P (42,14)	+ 0.3	+ 0.1
P (60,15)	+ 6.9	+ 5.0
P (44,26)	+ 0.1	+ 0.2
P (60,27)	+ 0.4	+ 0.4

Considering the data presented in Table 2, the model shows high correlation to field data for subsurface water elevation changes within the test pad. Although magnitudes of subsurface elevations are relatively consistent between modeling and the field, rise and decline rates between the two exhibit variations. Field conditions show maximum increases in piezometer elevations occurring concurrent with the injection phase to two hours post injection. Modeling, however, possesses a 2 - 3 hour delay in maximum mounding. Additionally, decline rates in the model are less than those present in the field. These differences of subsurface water elevations from the model over those in the field can be attributed to the higher permeability soil layer underlying the SM layer in the field, a condition that the model does not have the capability to duplicate.

SUMMARY AND CONCLUSIONS

This report documents results from Phase II deployment effort of the WIDE system at the Battelle's West Jefferson Filter Bed area, beginning August 2002 and continuing through April 2003. The construction activities involved the installation of over 2000 Prefabricated Vertical Wells (PVWs), fabrication and assembly of the surface piping manifold and header systems, installation and commissioning of the vacuum extraction and computer-controlled pump injection systems, and the configuration and hook-up of the 3M cesium filter system.

The field testing was staged on a field pilot-scale area measuring 15 feet x 15 feet positioned within Plot #2. Over the course of an 86-day injection program, commencing 20 November 2002 and ending 13 February 2003, a total of 29,072 gallons of water were injected into the subsurface in support of two testing cycles of the injection system commissioning efforts. The testing cycles were: Cycle #1) Injection under gravity feed using a "falling-head" technique, and Cycle #2) Pressurized injection in both gradual and aggressive approaches. This injection occurred over a period of 21 days, and a breakdown of injection days and volumes is summarized in Table 3.

Table 3: Summary of Injection Days and Volumes

Date	Volume Injected (gallons)	Date	Volume Injected (gallons)
20 Nov 2002	1872	30 Jan 2003	1200
21 Nov 2002	572	31 Jan 2003	1200
22 Nov 2002	815	3 Feb 2003	1200
9 Jan 2003	500	4 Feb 2003	2000
15 Jan 2003	490	5 Feb 2003	2000
16 Jan 2003	700	6 Feb 2003	2000
17 Jan 2003	700	10 Feb 2003	2400
20 Jan 2003	1150	11 Feb 2003	2400
21 Jan 2003	750	12 Feb 2003	2400
22 Jan 2003	1123	13 Feb 2003	2400
29 Jan 2003	1200		

Monthly Totals: Nov (3,259 gal.), Jan (9,013 gal.), Feb (16,800 gal.)

From field activities and modeling performed to date, the following conclusions can be established:

i. WIDE implementation on a 15' x 15' grid testing area showed the ability to raise subsurface water elevations using either gravity feed or pressurized injection.

ii. Pulse injection from pumped delivery was determined to be more effective than gradual injection in rising and maintaining subsurface water elevations to levels necessary for saturation of those layers of maximum cesium contamination.
iii. Multiple cycles of pulsed injection show the ability to increase / maintain groundwater elevation levels over that of single pulsed injection cycles.
iv. Testing the establishment of an air curtain to maintain subsurface water elevations was inconclusive due to weather complications (i.e. low temperatures resulted in freezing pipes during testing period).
v. Computer modeling can be employed to effectively simulate steady-state groundwater elevations.
vi. Modeling results compare reasonably well with field data for specific testing cycles. The model can provide understanding liquid response to planned injection strategies, and development of configurations for the advancement of wetting fronts prior to injecting the Lixiviant. It is recommended that during Lixiviant injection phase, real-time monitoring coupled with modeling be used to control and direct the remediation work for effective implementation.

Prior to using the WIDE system for remediation effort in Phase III, it is recommended that all three sequences of the system commissioning be tested. Information included in this report may be used for selecting operational parameters for calibrating the vacuum extraction system, optimizing the liquid injection parameters, and controlling the WIDE system hydraulic balance.